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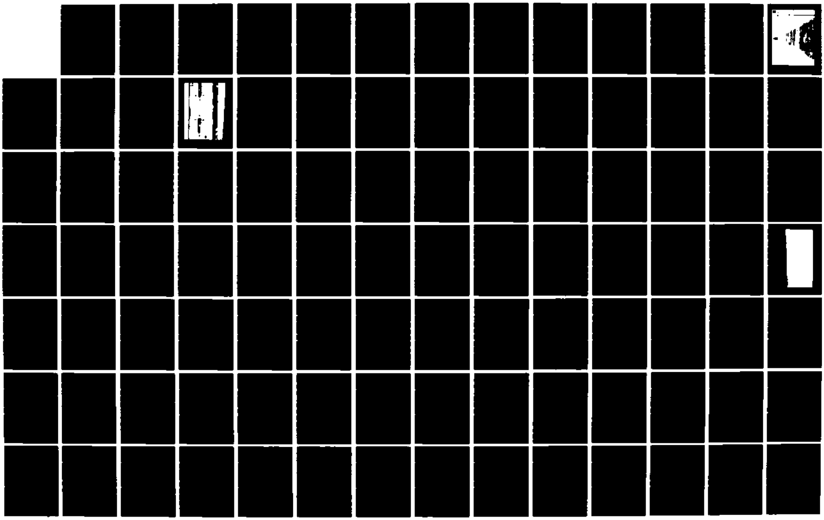

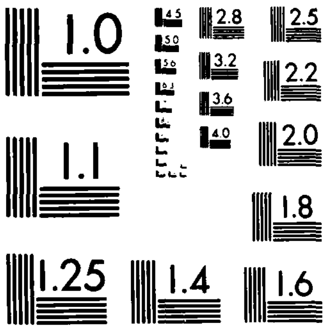

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Investigation of Wide-Aperature Localizer Array and Monitor Performance

Avionics Engineering Center
Department of Electrical and
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Ohio University
Athens, Ohio 45701

April 1983

Final Report

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16. Abstract

Measurements performed on the single array 22-8, the Wilcox 16-element, and the Redlich 14-element wide aperture localizer arrays are documented. Monitor fault tests are presented for the Redlich array. In addition, a section documenting the single array patterns for the Log Periodic Dipole (LPD), the O-Ring traveling wave, and the Folded Dipole antennas is presented.

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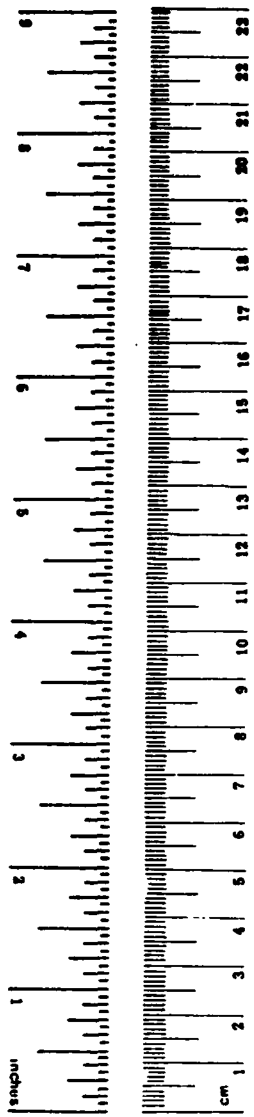
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

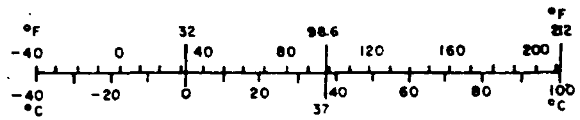
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

An FAA requirement for a wide-aperture, capture-effect localizer system has led to the investigation of three distinct arrays. These are the Alford 22-element, the Wilcox 16-element and the Redlich 14-element systems. Of the three arrays only the Alford system has previously undergone any in-depth testing, thus it was chosen first for implementation and testing. Because the Alford array uses 22 elements of which 8 are used to radiate clearance signals, the array will be called 22-8.

After installation of the 22-8, shown at the Tamiami Test Site in figure 1, it was decided that two other systems recently designed by the Wilcox Electric Company and Dr. Robert Redlich respectively, should [illegible] further investigated. These more recent designs use 6 to 8 fewer [illegible]ments to obtain predicted performance similar to that of the 22-8 system [illegible] thus offer a potentially significant advantage. In order to ensure that [illegible]ese newer designs perform at least as well as the 22-8, baseline data [illegible]en collected on the 22-8 system recently installed at the Tamiami Air[illegible] Miami, Florida. This report documents the results of the investigation and measurements of the fundamental array characteristics.

Following the above investigation, the Redlich 14-element localizer array was chosen for monitor implementation. The results of monitor fault correlation tests are included in this report. The field data is contained in appendix A.

In addition to the specific arrays investigated, a comparison of the three types of traveling wave antenna elements currently in use by the FAA is documented.

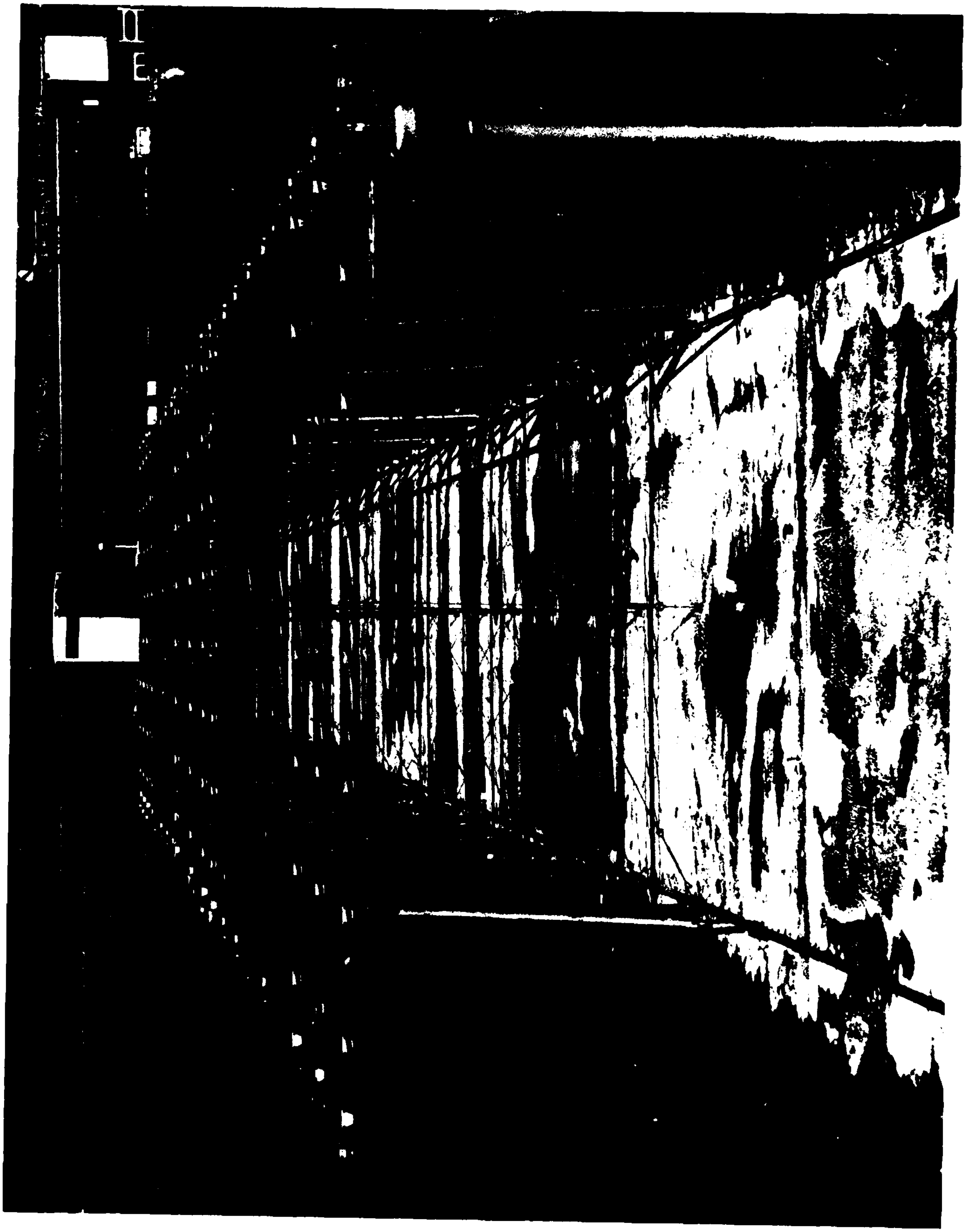


Figure 1. 22-8 Ring Antenna Array.

BACKGROUND

Nearly a decade ago a major objective of the FAA SRDS was to develop a stable of localizer array configurations which would be available to serve sites possessing different degrees of difficulty. One requirement was to have a basic array that was expandable, i.e., if the small aperture array was not performing adequately, then it could be expanded by merely having elements added with no rearrangement.

All arrays used 17-foot traveling wave elements. Accordingly, Andrew Alford Consulting Engineers developed the 8-element, 14-element and 22-element localizer arrays. The 22-element localizer array and one version of the 14-element array required auxiliary arrays to provide clearances to ±35° [1]. The 22-element with an 8-element clearance array was tested at Boeing Field, Seattle, Washington in 1972. One example of the 14-element which used but a six-element clearance array, was tested at Tulsa in 1971.

Because of the extensive amount of antenna and transmission-line hardware in these antenna systems, it was deemed desirable to combine the physical arrays so that one array would serve both the course and clearance transmitters. In 1974 Alford furnished a 14-6 combined array and Ohio University tested it thoroughly at the Tamiami site. This included monitor functions. [2]

Although plans at that time called for testing the combined 22-8 version, work to obtain a satisfactory monitor for the 14-6 consumed so much time and financial resource this 22-8 testing was never accomplished.

Revival of interest in a high-performance localizer array for Category III operations motivated the work with the 22-8 array. Involvement in the 22-8 work quickly impressed the workers that even though the array is combined, the 22-8 involves a considerable amount of hardware. This is particularly true when it is realized that this array must be monitored in an analog sense as well as in terms of fault detection.

While investigating the hardware problem and considering the tolerances that must be maintained in the distribution units to implement the array, considerable encouragement is provided for reducing the number of elements. New developments in the theory of array designs over the past decade has given encouragement that array designs with fewer elements may be capable of performing as well. Later sections of this report will investigate the performance of arrays with fewer elements (viz. 14 and 16 elements) and the baseline data presented here will be used to judge their quality.

DISCUSSION

The following sections contain information pertinent to each of the specific arrays and the monitor investigated. The conclusions obtained from each are included in the appropriate section.

INVESTIGATION OF THE 22-8, WIDE APERTURE, TWO-FREQUENCY, SINGLE-ARRAY LOCALIZER

INSTALLATION.

The original and only 22-8 localizer system tested by the FAA was installed at Boeing Field in Seattle, Washington [3] as a 22-element main-course array separate from an 8-element clearance array. The current requirement, however, is for a single array serving a two-frequency transmitting system. This testing requirement especially with respect to usable distance led to the necessity of designing a combiner network for the combined 22-8 system.

The design approach deemed most appropriate was to convert a currently available 14-6, two-frequency combiner unit, pictured in figure 2, to a 22-8 combiner unit. This was accomplished using an Alford Type 4874 common aperture combiner. The particular unit utilized also functions as a monitor for the clearance signals [5]. This portion of the combiner is not used in the altered distribution and thus only the main distribution portion is shown on the schematic of figure 3. In this particular system the clearance signal is attenuated by 6 dB and is then combined in an Alford Type 4782 power divider. The additions made to the 14-6 combiner to expand it to a 14-8 unit are shown in figure 4. This addition results in the same phase and attenuation for the two added lines as for those of the existing unit. Note that only 1/2 of the combiner is shown in the schematic. The right portion is identical to that shown. Figure 4a shows a block diagram of the system as installed.

The antenna lines which do not require the clearance signal are then attenuated by 1.5 dB to obtain the proper distribution. The combiner is then fed by an Alford 22-element main course distribution unit and a Wilcox Type I 8-element self-clearing array distribution unit. The 8-element self-clearing array is used as the clearance array in the 22-8 system.

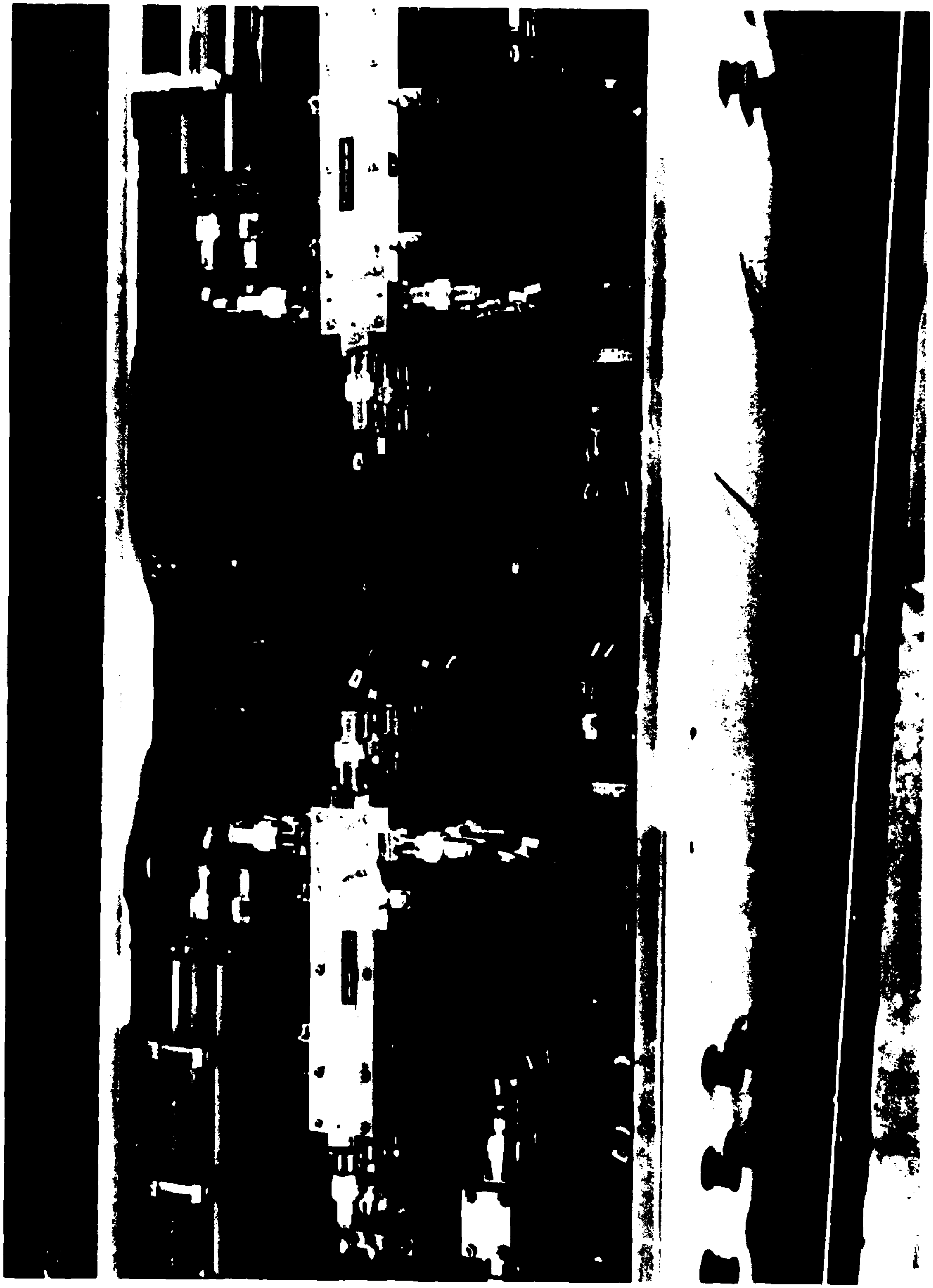


Figure 2. 14-6 Combiner Unit.

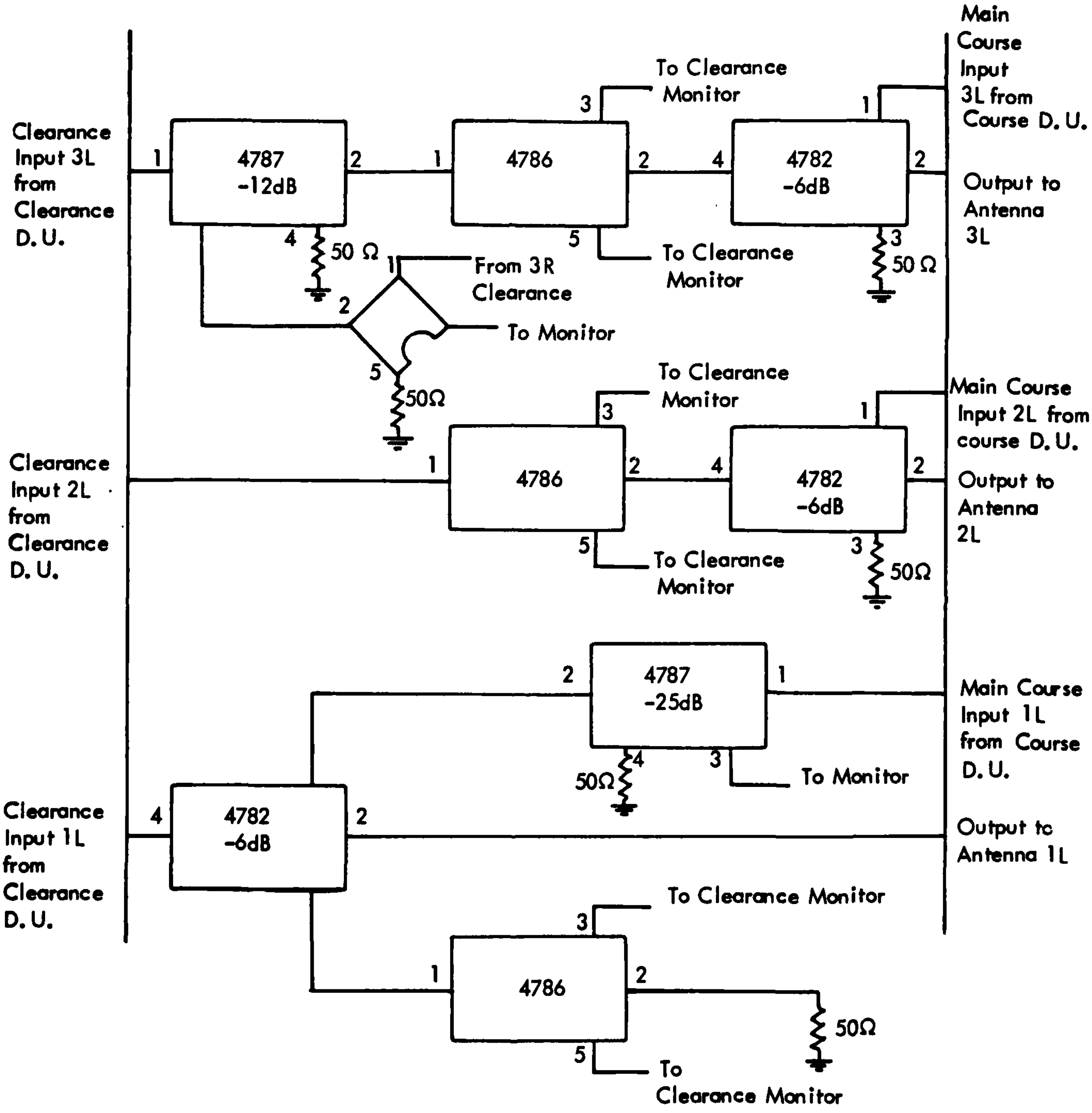


Figure 3. Schematic Diagram of the Alford 14-6 Combiner.

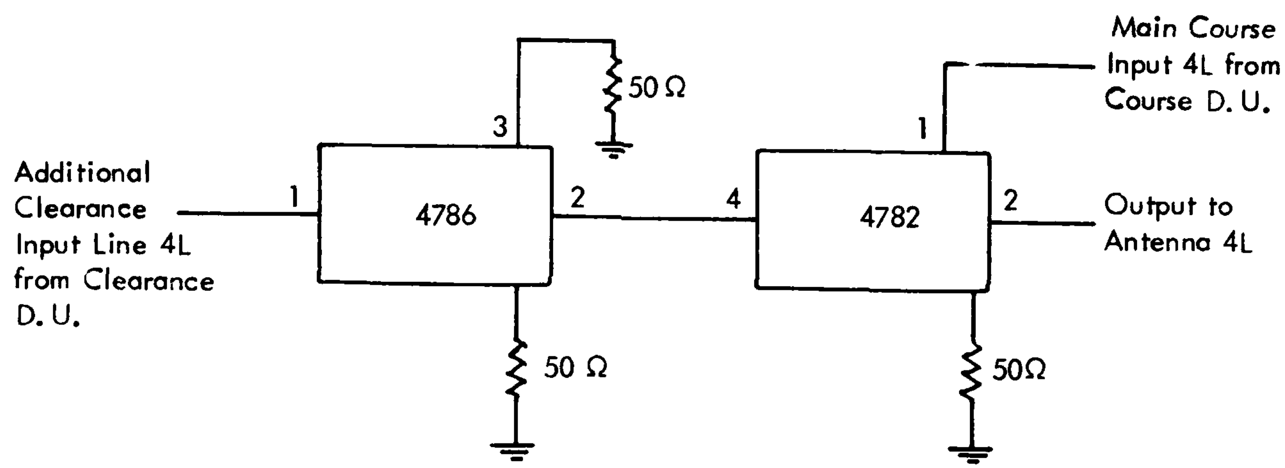


Figure 4. Additions to 14-6 Combiner.

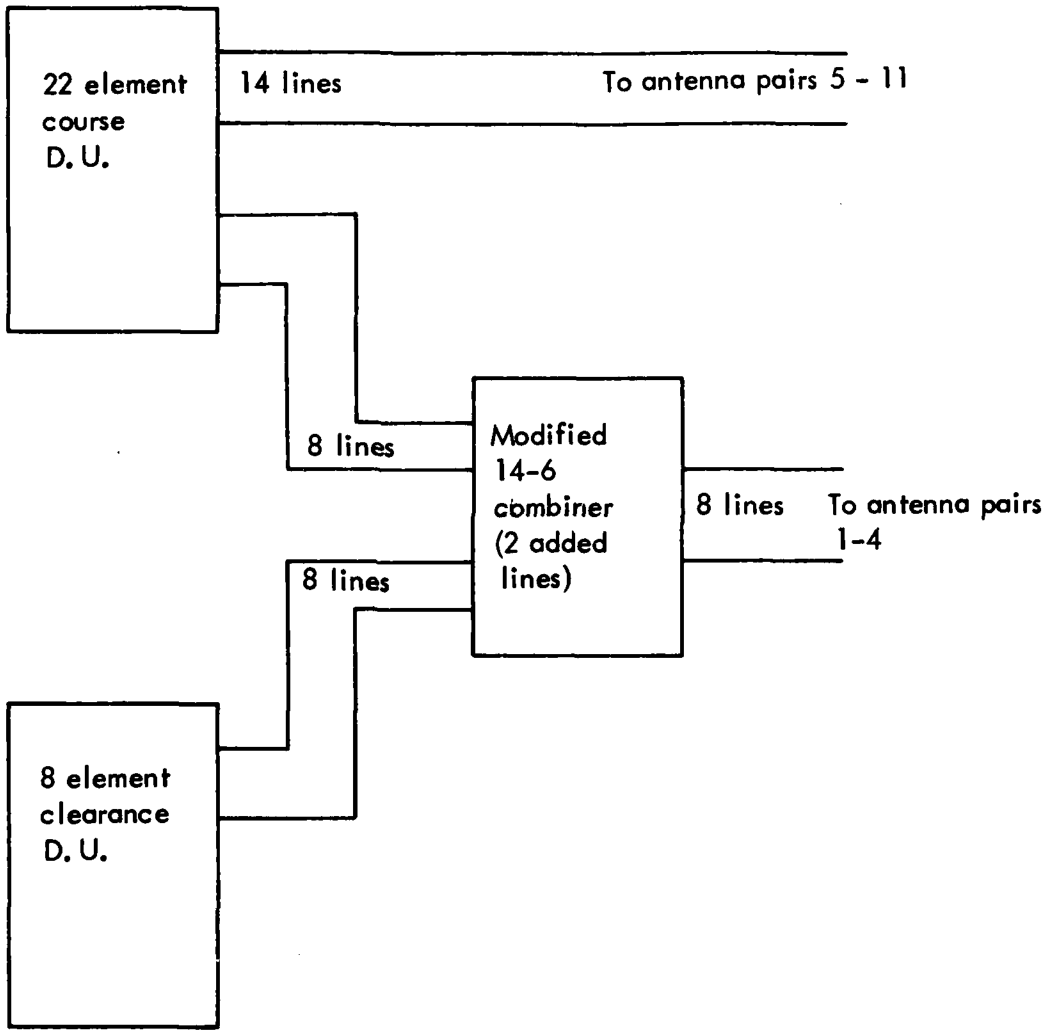


Figure 4a. Block Diagram of Installed Combiner Unit.

MEASUREMENTS.

Usable distance measurements were performed in accordance with the United States Standard Flight Inspection Manual 8200.1 at both the 18 nautical mile and 10 nautical mile distances for ILS Sectors 1 and 2 respectively. The results of these measurements are shown in figure 5. The measured values with the tolerances as published in 8200.1. are compared. From the figure it is noted that the main course usable distance of 18 nautical miles is met without difficulty. This is with an input power at the distribution unit of 4.5 watts of carrier power. The clearance usable distance requirement, however, is below the required 5μv level in localizer clearance Sectors 1 and 2. This discrepancy is attributed to the input power level only and may, of course, be overcome with increased clearance power or by the use of a more efficient combining method of the course and clearance signals.

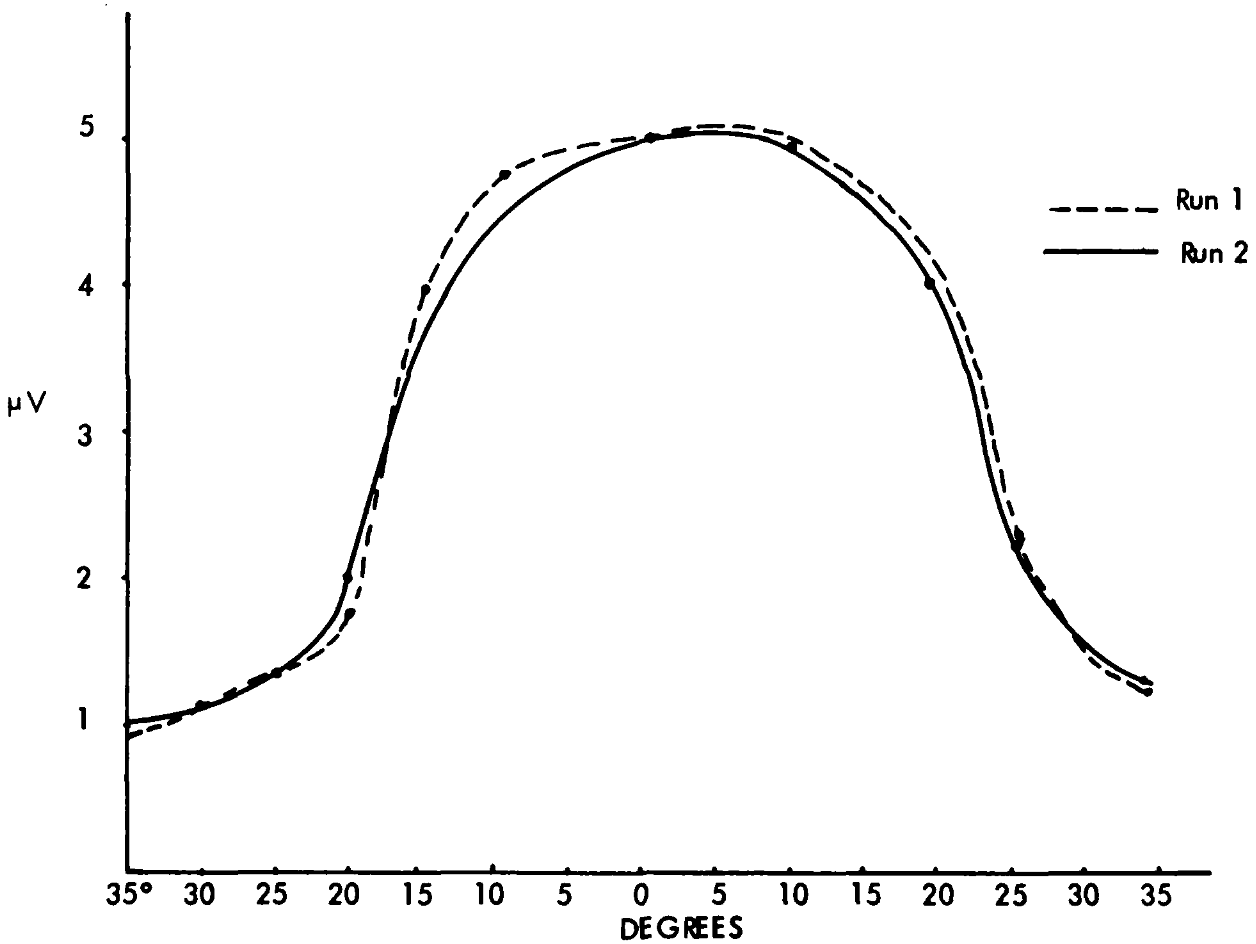
The main concern in the implementation and testing of a new wide-aperture localizer array is ensuring that the performance specifications are at least equal to the performance of the 22-8 system. To verify the performance of future systems, radiation pattern checks of both the CSB and SBO signals for the main and clearance portions of the 22-8 array were made for baseline purposes. These measurements were recorded using the Ohio University micro-lab test package in a light aircraft. Radial flights at a distance of 5 nautical miles were flown for each of the radiated signals. The AGC levels of the receiver were recorded with a calibration curve following the measurements to ensure accurate relative RF measurements. The reference used was an IFR 401L Signal-standard carried on board the aircraft.

Figure 6 shows the main course CSB pattern as measured using the above process. The measured carrier beam width is 4.8° and the highest side lobe is 24 dB down from the main lobe. The carrier beam width is measured at .8° wider than that published [5] and the maximum side lobe is somewhat higher than the -30 dB value expected of the 22-element main course array. A portion of this difference may be attributed to the difference in frequency between the measured data and the calculated data. All measurements were made at a frequency of 111.9 MHz.

The measured course SBO radiation pattern for the 22-element main course array is shown in figure 7. The sideband lobe peaks occur at ±3° degrees and the lobe halfpower widths are measured to be 3.4°. In addition, the maximum sidelobe occurs at 7° to the right of centerline and is -22 dB down from the maximum sideband lobes. These values compare fairly well with those published earlier, i.e., sideband lobe peaks at ±3°, sideband lobe width of 3° and -30 dB for the maximum sidelobe.

The clearance radiation patterns for the 8-element unit are presented in figures 8 and 9. Note the small difference between the sideband lobe peaks and the null on centerline. This is due to the fact that the clearance array was slightly mis-phased during the measurements and this would not be a problem in a properly phased system. Also the clearance portion of the array is slightly misaligned with centerline resulting in the carrier peak and the sideband nulls occurring slightly to the left of centerline.

Parameter	8200.1 (CHG32)	Measured Value
Usable Distance	5 μV @ 18 NM	9 μV @ 18 NM
Coverage	5 μV @ 10 NM Sectors 1 and 2	See Graph below



10 NM Radius 8-Element Clearance Usable Distance

Figure 5. Comparisons of Usable Distance for the 22-8 Localizer.

Ant #	Course CSB		Course SBO		CLR CSB		CLR SBO	
1L	0.009	0.5°	−0.005	0.6°	0.000	0.0°	0.000	0.0°
2L	0.000	0.0°	−0.098	1.7°	0.011	1.1°	−0.040	0.6°
3L	−0.012	−2.1°	−0.137	1.3°	0.034	3.6	−0.012	−0.4°
4L	−0.036	−1.5°	−0.080	0.0°	0.021	4.7	−0.018	−1.9°
5L	−0.002	−1.9°	−0.111	0.9°	—	—	0.016	−2.0°
6L	−0.011	0.0°	−0.094	0.0°	0.011	−3.5	−0.010	−4.2°
7L	0.008	−2.5°	−0.030	1.6°	0.009	−3.2	—	—
1R	−0.029	1.0°	−0.005	0.9°	0.030	0.0	0.000	0.6°
2R	0.000	0.5°	−0.068	1.9°	0.012	3.4	−0.040	1.0°
3R	−0.042	−1.5°	−0.098	1.9°	0.028	−3.6	−0.002	0.4°
4R	−0.046	−0.5°	−0.080	0.3°	0.023	−5.3	−0.012	−1.0°
5R	−0.002	−0.6°	−0.051	0.7°	—	—	0.016	−1.0°
6R	−0.013	1.0°	−0.054	0.0°	0.007	−3.9	0.000	−1.4°
7R	0.007	−1.2°	−0.010	−0.5°	0.001	−2.9	—	—

Table 1. Change in Measured Distribution Unit Output Values from Nominal for the Redlich Localizer.

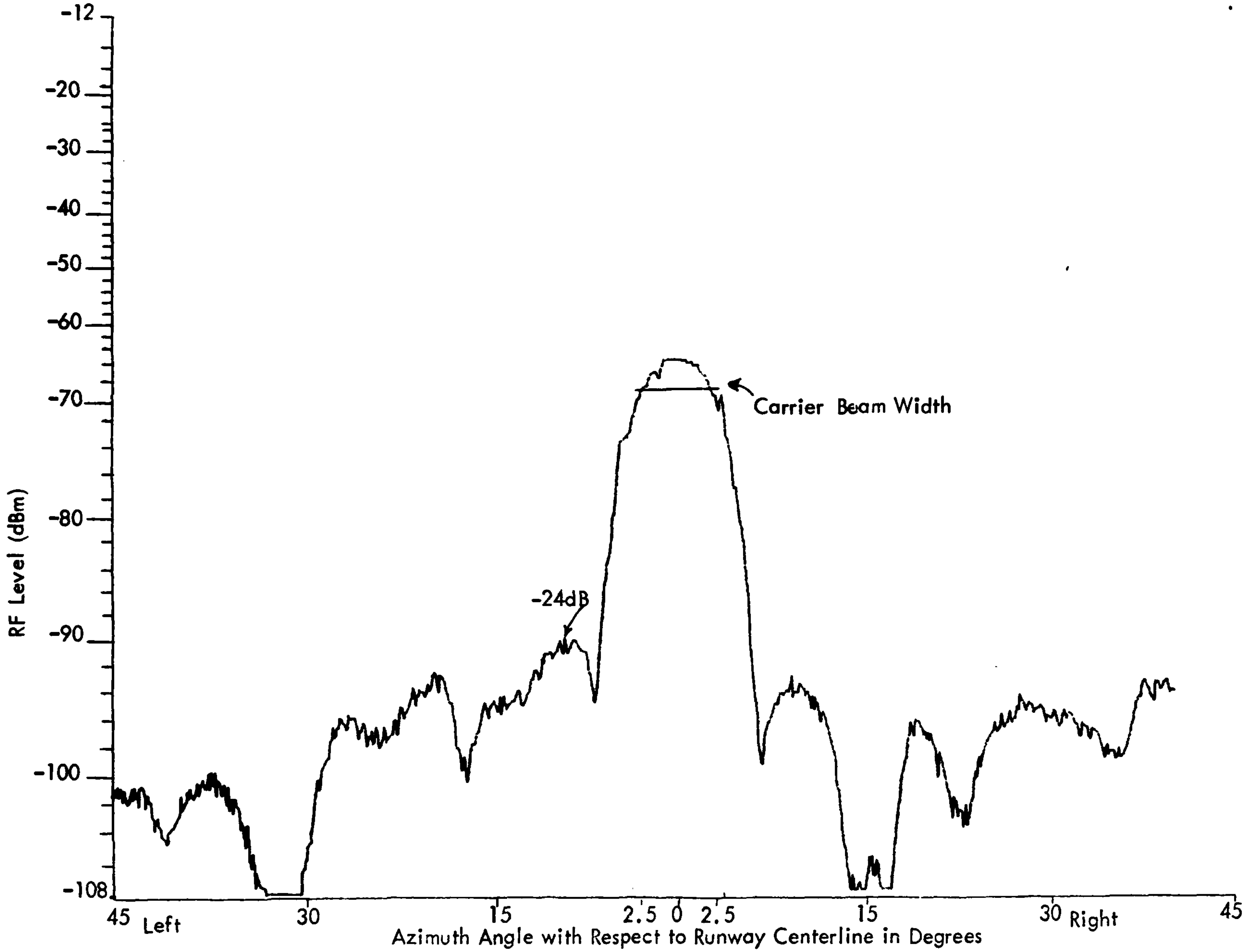


Figure 6. Measured Course CSB Radiation Pattern for the 22-8 Localizer Array.

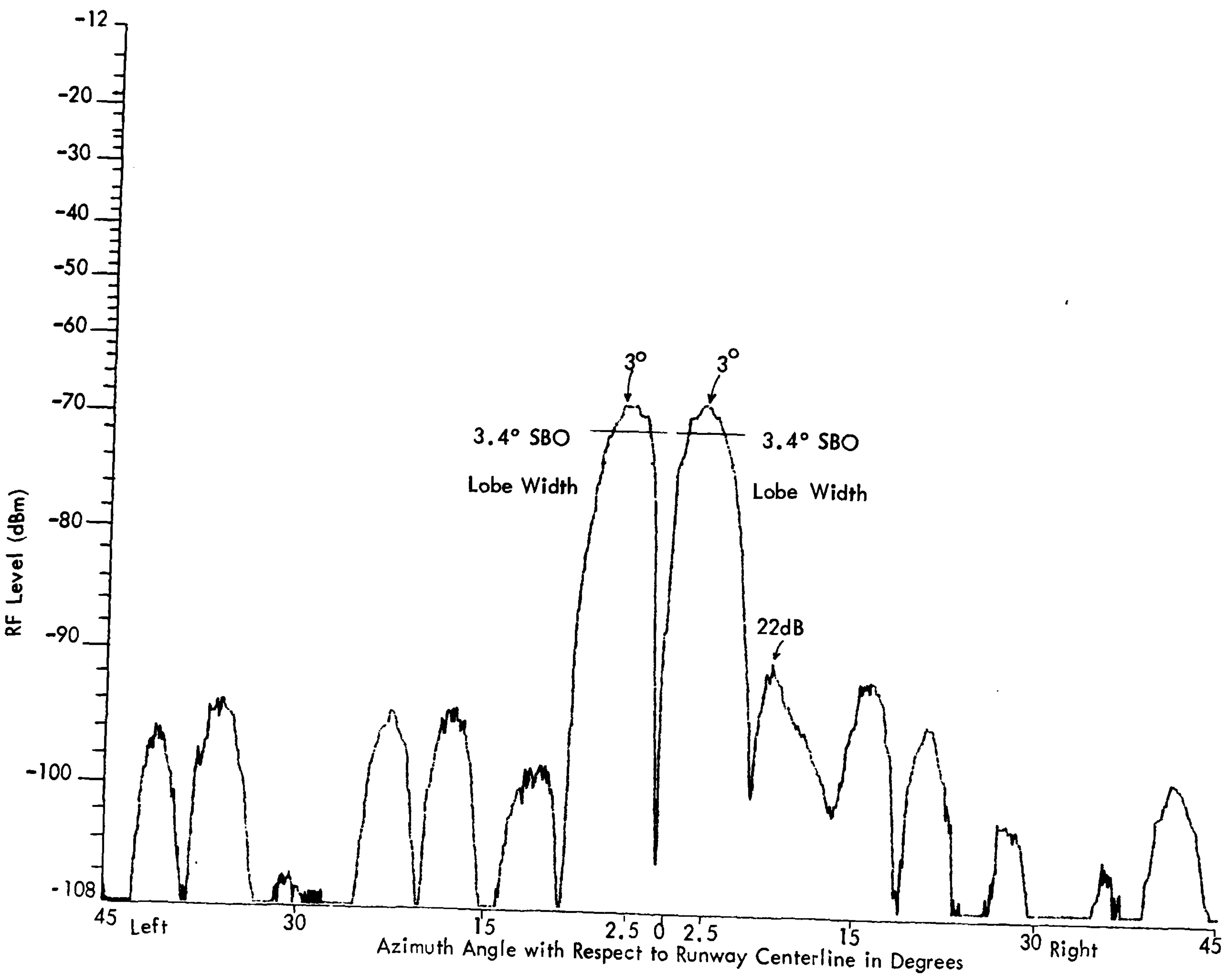
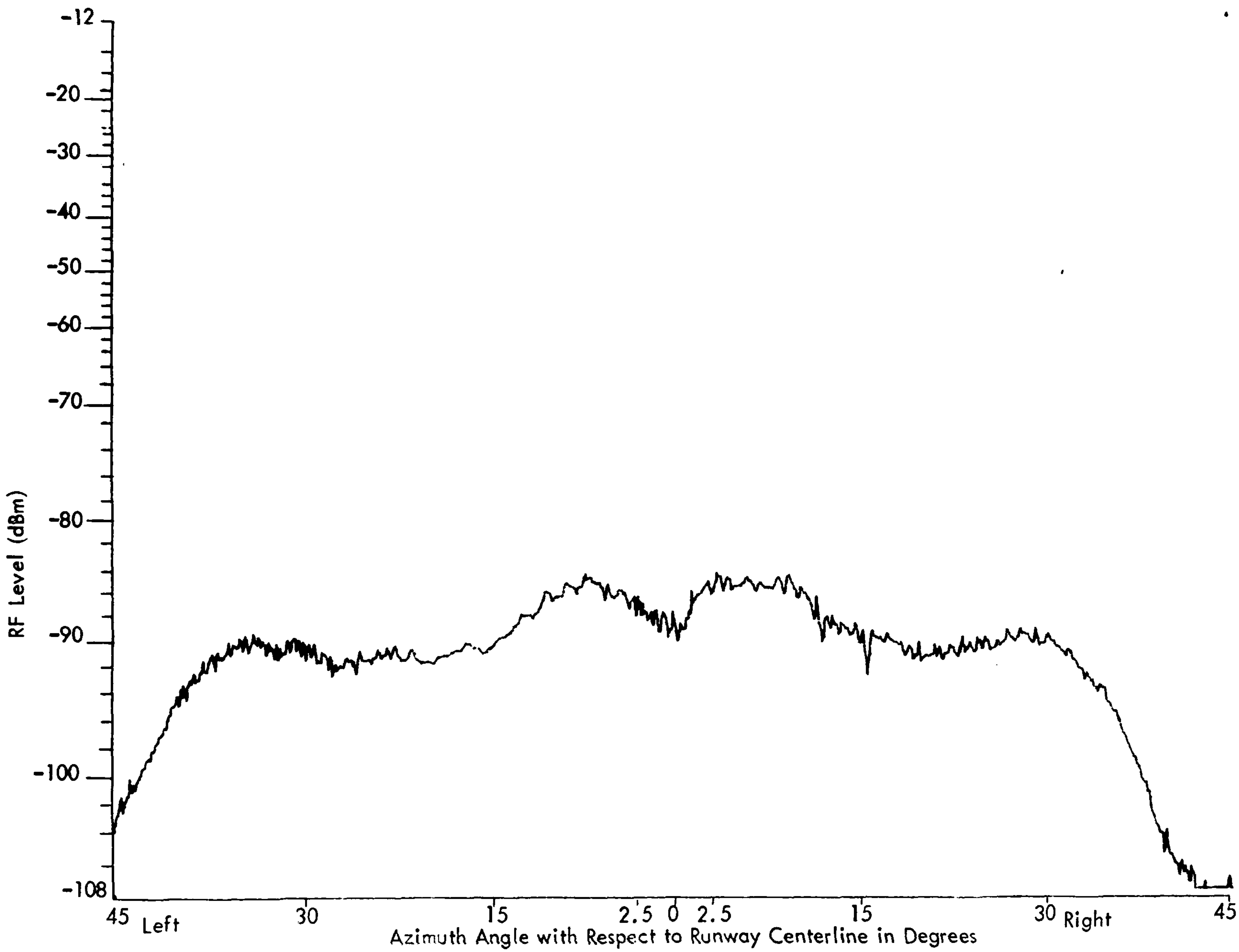


Figure 7. Measured Course SBO Radiation Pattern for the 22-8 Localizer Array.



Fig[illegible]3. M[illegible]d Clearance SBO Radiation Pattern for the 22-8 Localizer Array. S[illegible] is mis-phased, res[illegible]ting in no centerline null.

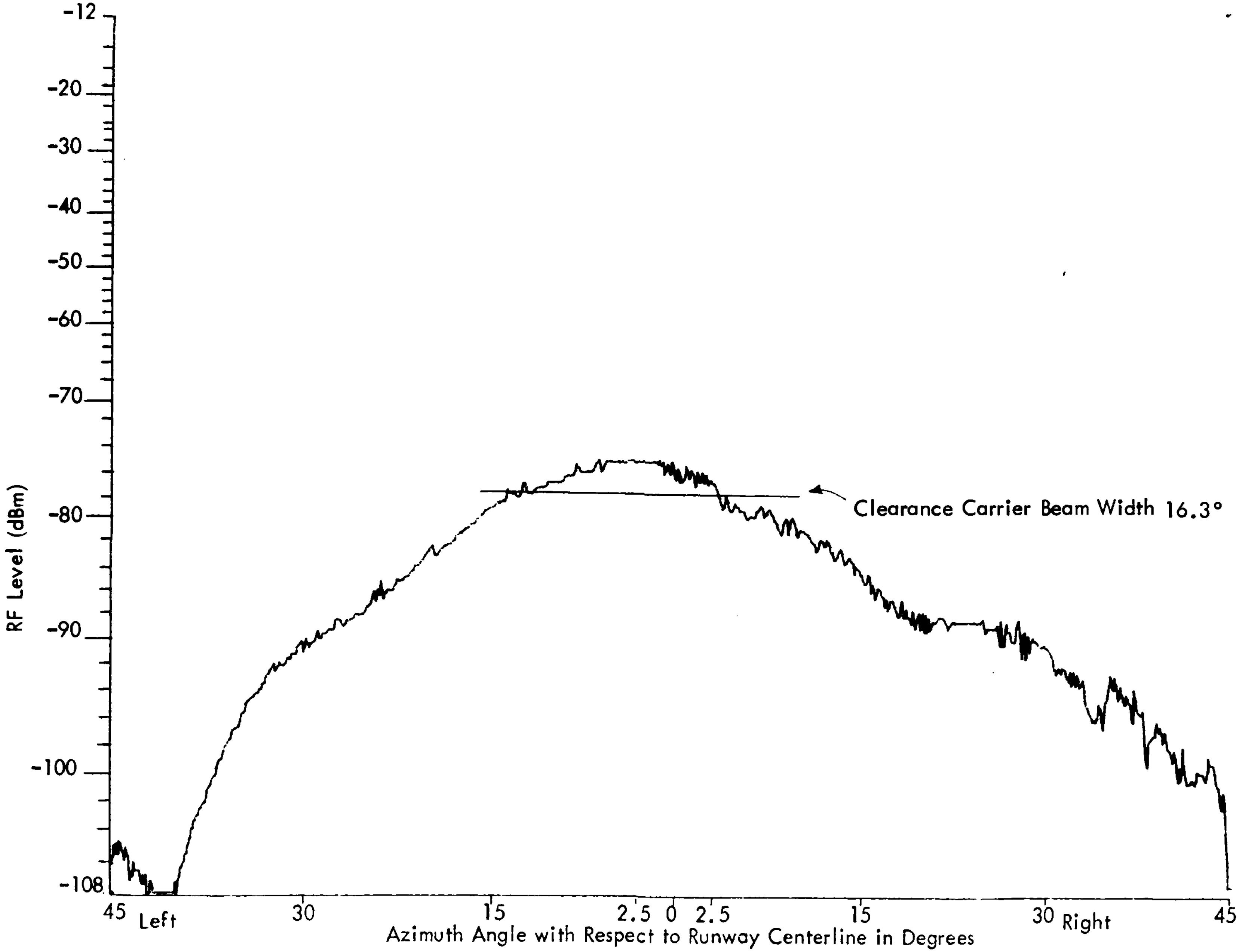


Figure 9. Measured Clearance CSB Radiation Pattern for the 22-8 Localizer Array.

CONCLUSIONS.

Airborne measurements on the 22-8 combined two-frequency localizer installed at the Tamiami Airport, Miami, Florida, have resulted in the following conclusions:

1. The usable distance on centerline at 18 nautical miles was found to be 9μv with an input power level of 4.5 watts at the distribution unit input. This is well above the 5μv tolerance level as established in the Standard Flight Inspection Manual 8200.1. [6]

2. The clearance usable distance was found to be as much as 4μv below the 5μv level required in clearance Sectors 1 and 2. This was also with an input power level of 4.5 watts at the clearance input to the distribution unit. This problem is attributed to the 6 dB of attenuation added in the combining method used in this particular application.

3. The course carrier (CSB) halfpower beam width is measured to be 4.8° and the maximum side lobe is -24 dB below the on-course peak over ±45° azimuth.

4. The course sideband (SBO) peak lobes occur at ±3° and are 3.4° in halfpower beam width. The maximum SBO sidelobe is -22 dB below the sideband peak lobes in the ±45° azimuth area.

5. The clearance array carrier beam width is 27 degrees with no sidelobes within ±45° of centerline.

6. The clearance array sideband (SBO) pattern shows only a 6 dB difference between the sideband peaks and the centerline minimum.

INITIAL INVESTIGATION OF THE REDLICH 14-ELEMENT, TWO-FREQUENCY, SINGLE-ARRAY LOCALIZER

Two other wide-aperture, two-frequency localizer arrays have been recently designed. One by the Wilcox Electric Company, utlizing 16 elements and the other by Dr. Robert Redlich, utilizing 14 elements. These two arrays are designed to have performance characteristics similar to those of the 22-8 system, but have reduced complexity and economic advantages obtained through the use of fewer elements. This section, in particular, compares the calculated results of the Redlich localizer array with that of the 22-8. In addition, results of some initial field experiments performed at the Ohio University ILS test site, Tamiami Airport, Miami, Florida, are given.

The Redlich localizer design was furnished in schematic form to Ohio University engineers. This schematic was then used to construct the actual distribution unit per the specified current distribution and phasing. The fabrication and testing of the unit were performed by Ohio University engineers and technicians.

OBJECTIVES.

The main objectives of this section are to determine the performance of the Redlich array and to determine whether or not this performance meets or exceeds the crucial reference values established by the 22-8 tests.

The individual items to be compared are the following:

1. Course CSB* patterns to include half-power beamwidth
2. Course SBO* patterns
3. Clearance CSB and SBO patterns
4. Individual and combined DDM patterns
5. Usable distances for course and clearance

---

* CSB refers to carrier plus sideband energies while SBO represents suppressed carrier, i.e. sideband only.

RESULTS OF CALCULATIONS AND MODELING.

Computer calculations of the course and clearance portions of the array have been made using the current distribution and array spacings provided. The results of these calculations are presented in figures 10 through 15. Each plot presented in these figures will now be discussed in detail.

Figure 10 shows the comparison of the calculated CSB patterns for the 22-8 and the Redlich arrays. The two patterns are almost identical in the main lobe area with the only difference being in the level of the highest sidelobe. The highest level on the 22-8 pattern is -22 dB below the main lobe, while that of the Redlich array is -19 dB below the main lobe. This is not considered a significant difference on the course CSB patterns and no detrimental effect on the course should be produced by this difference. This is because scattered CSB energy causes little effect on path structures. This is in contrast to the SBO patterns which are critical.

Referring to figure 11, the calculated plot of the course SBO patterns for the Redlich and 22-8 arrays, it is evident that the SBO peaks occur at 3° and have a width (1/2 half power) of 3°. These values are identical to those of the 22-8 patterns. Note also that within ±45° no sidelobe levels occur in excess of those of the 22-8 array.

The clearance radiation patterns for the Redlich array are plotted in figures 12 and 13. These patterns are substantially different from those of the 22-8 since the 22-8 uses the 8-element Type-I self-clearing array to provide clearance. See figures 14 and 15. The Type-I array is not optimized to provide minimum power on centerline as does this portion of the Redlich design; hence, no attempt will be made to compare the clearance radiation patterns directly with the 22-8. By minimizing energy on the centerline where the course array is dominant, greater signal strength is available for the clearance region.

MEASUREMENTS AND ANALYSIS.

A series of measurements were performed to measure the performance of the Redlich localizer array under optimum conditions. These tests were conducted at the Tamiami site and consisted of both ground and airborne checks. The airborne tests were conducted using the Ohio University Mark III Mini-lab inspection package in a Beechcraft Model 36 aircraft while all ground checks were made with the Micro-lab test package and the Portable ILS Receiver (PIR). In addition, a Warren-Knight Model 83 theodolite was used as a ground-based reference.

A series of measurements were performed on the various components involved in the construction of the array. These checks were made to provide a degree of confidence in the flight measurements to follow.

Table 1 contains the measured current distributions as recorded at the antenna ports of the distribution unit. These values were used as the

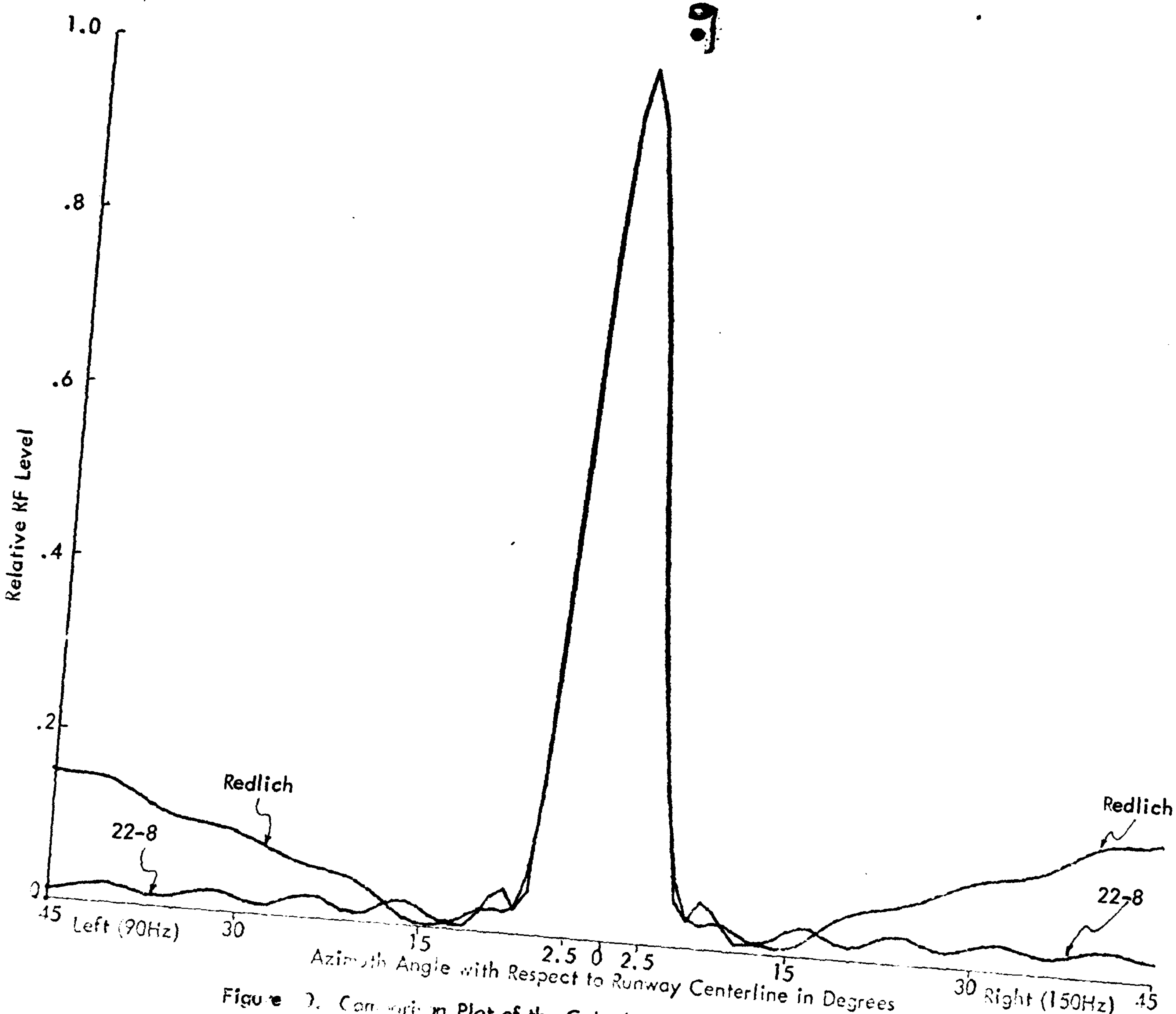


Figure 9. Comparison Plot of the Calculated Redlich and 22-8 Course CSB Patterns.

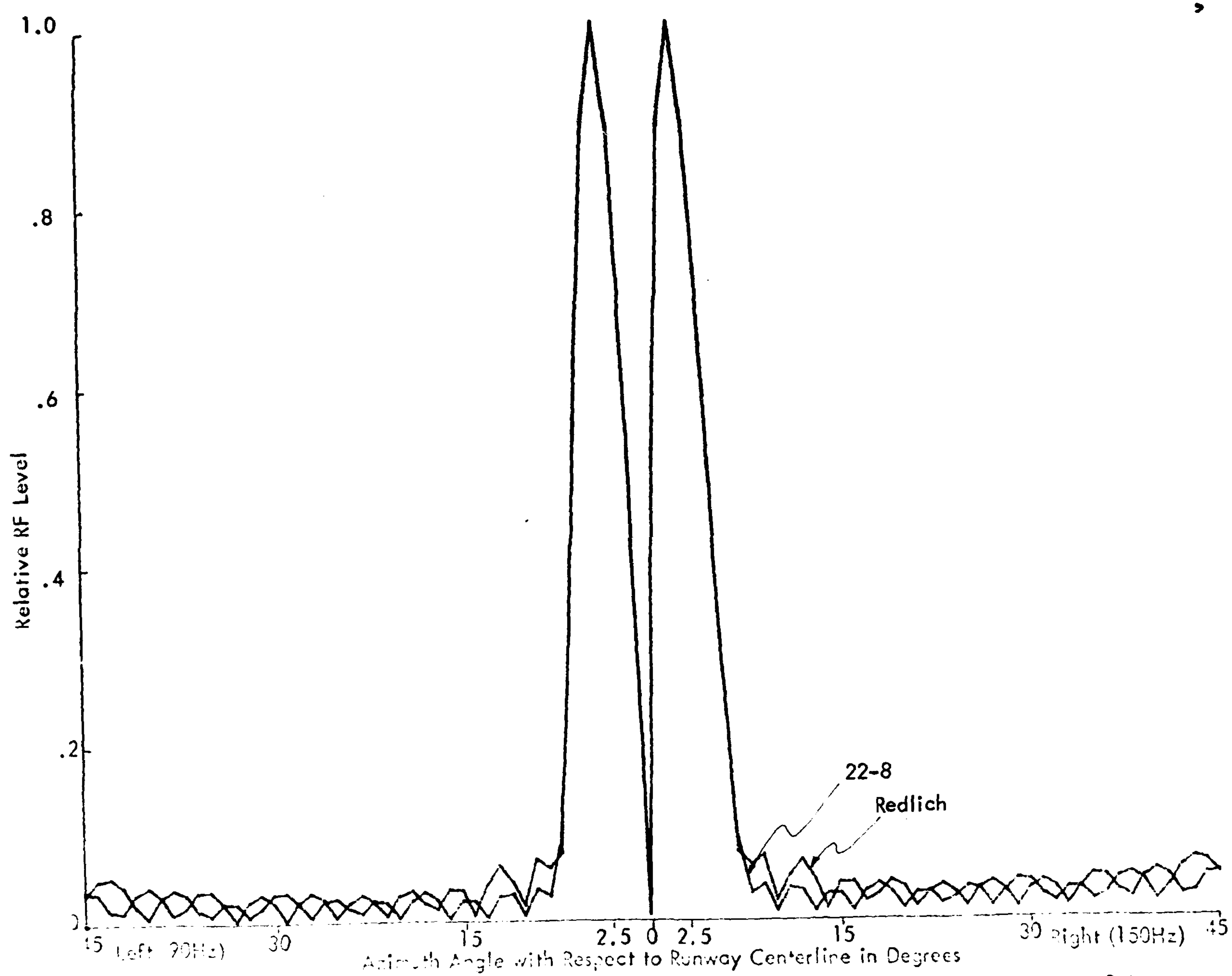


Figure 11. Comparison Plots of the Calculated Course SBO Patterns for the Redlich and 22-8 Arrays.

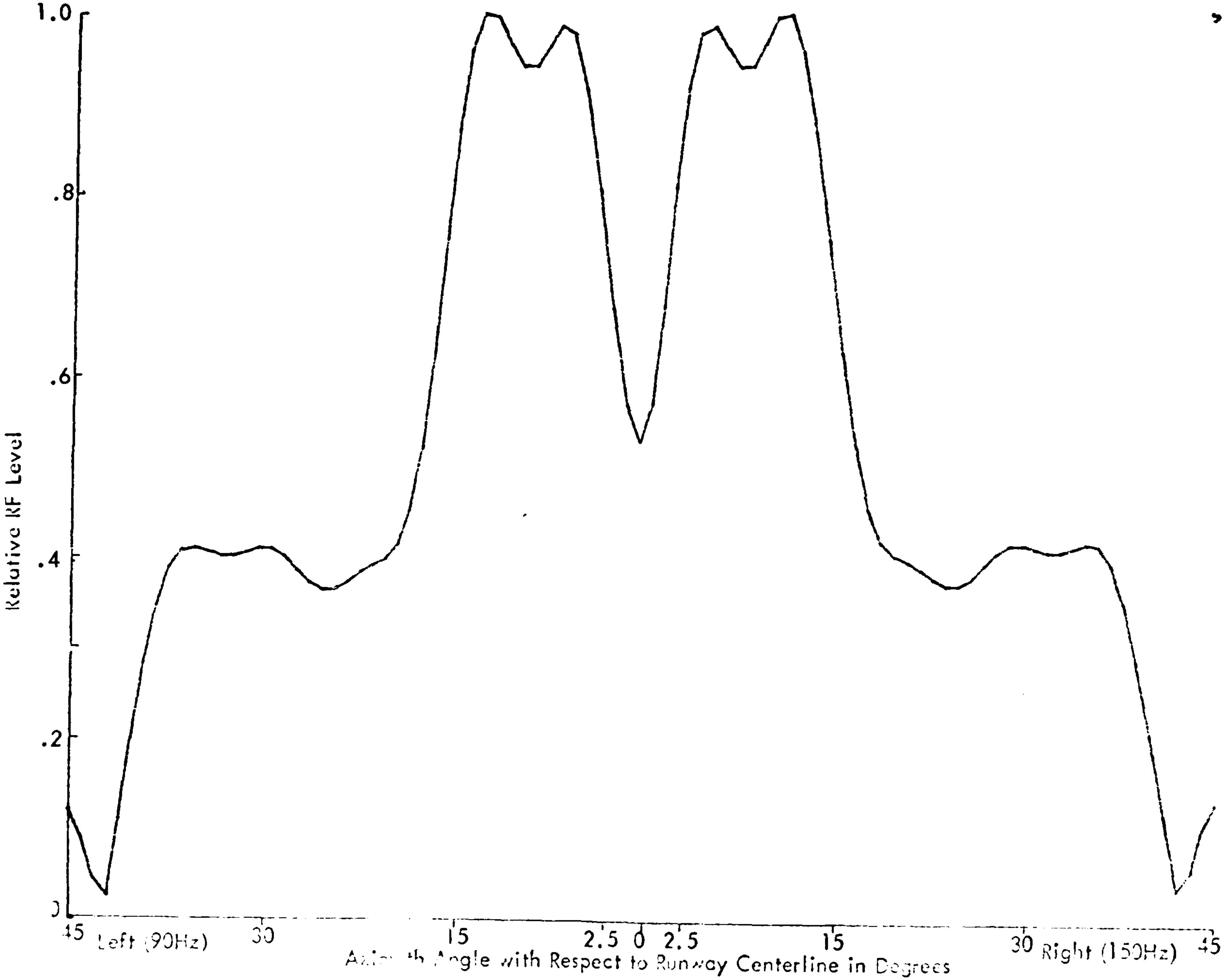


Figure 1 Calculated Plot of the Redlich Clearance CSB Pattern.

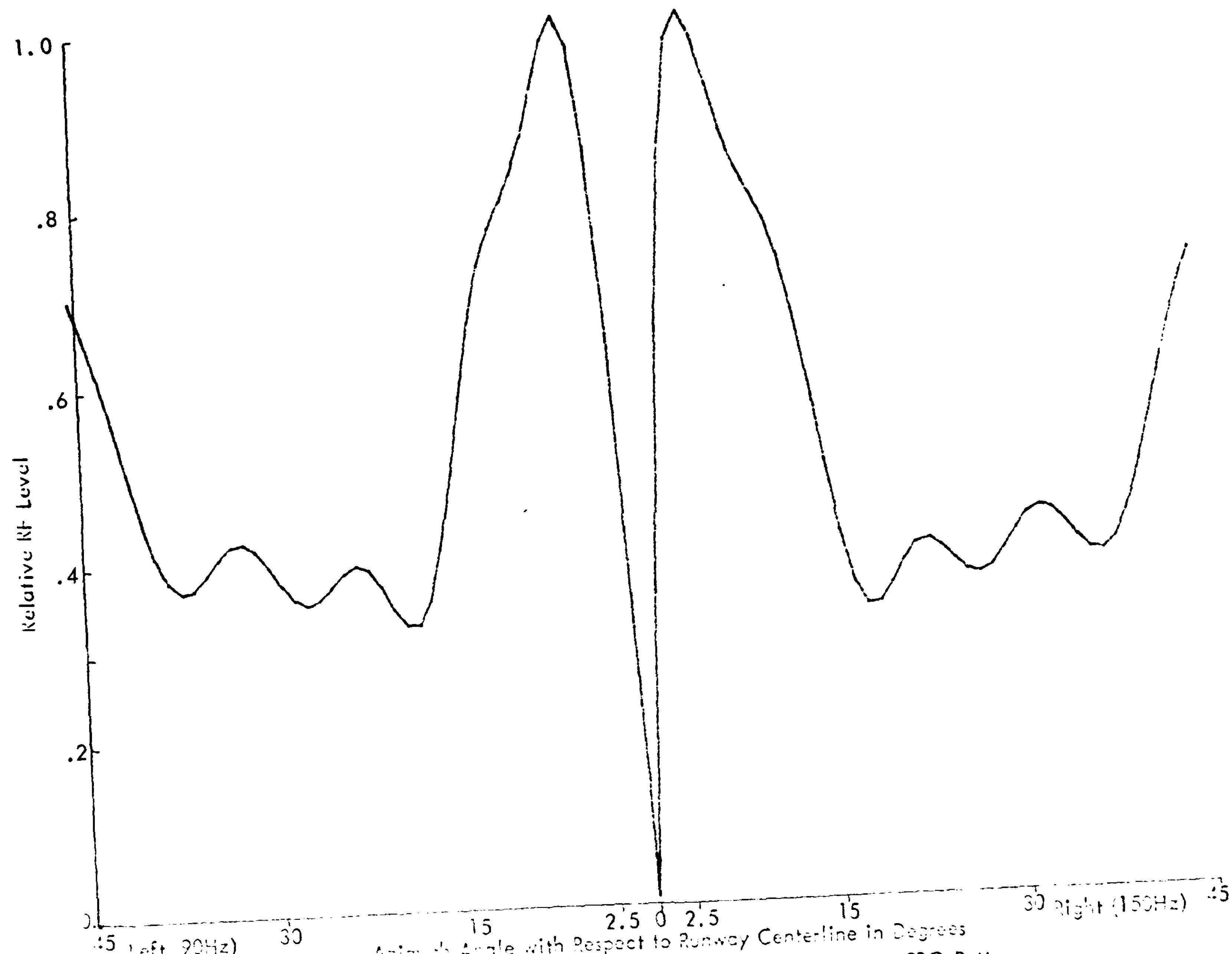


Figure 13. Calculated Plot of the Redlich Clearance SBO Pattern.

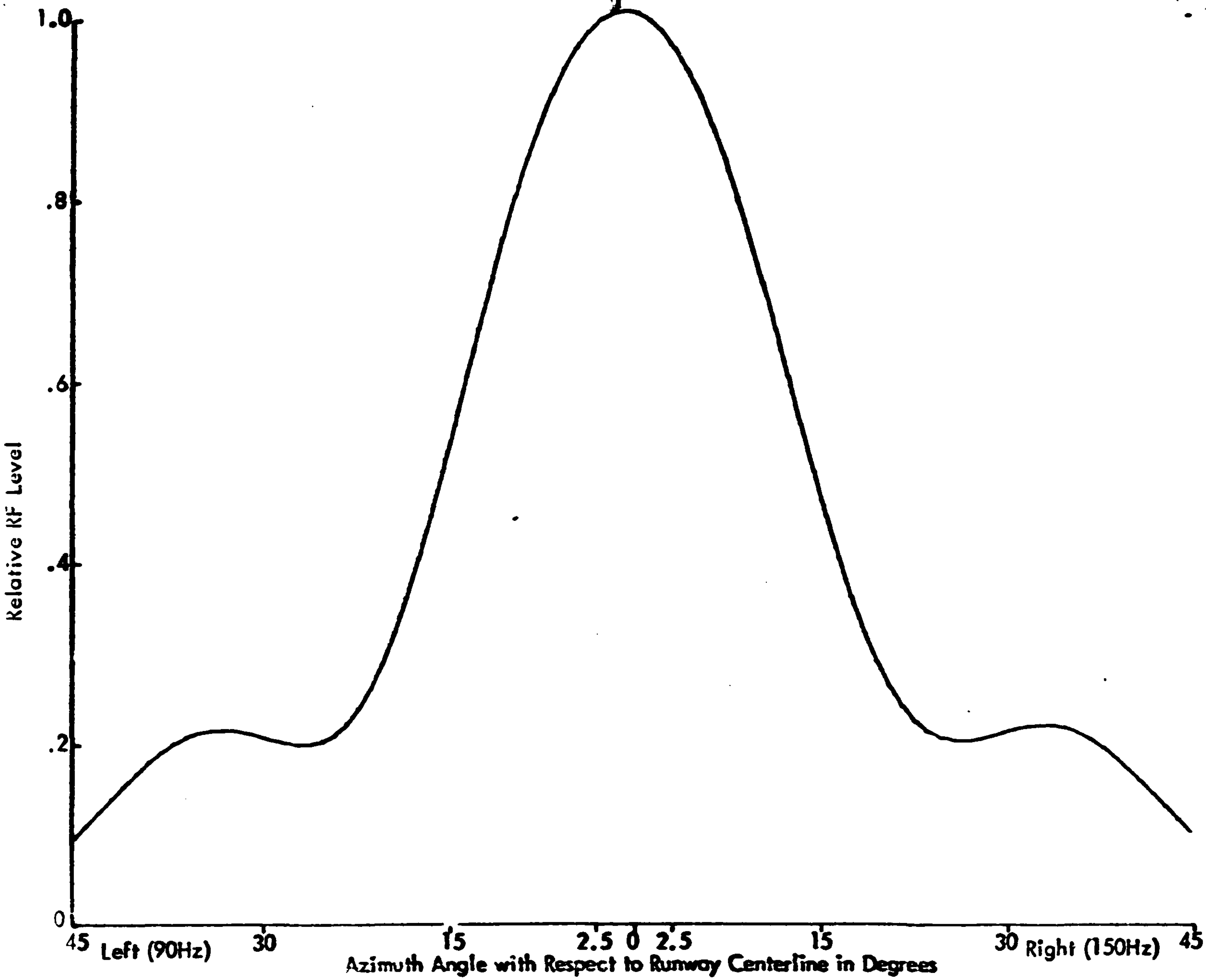


Figure 14. Calculated Plot of the 22-8 Clearance CSB.

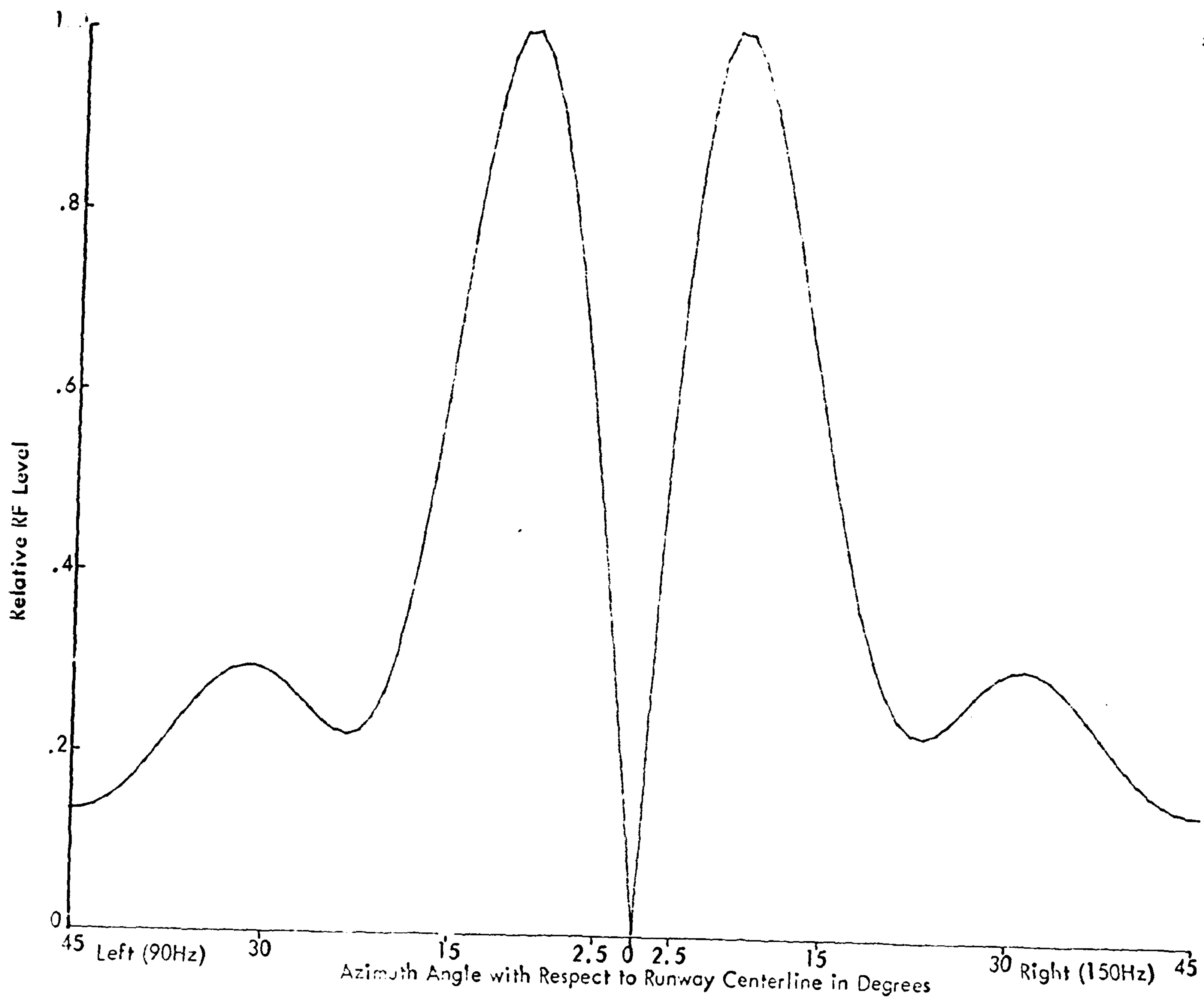


Figure 15. Calculated Plot of the 22-8 Clearance SBO Radiation Pattern.

input to the localizer model and the patterns which resulted are compared against those of the ideal distribution unit values in figures 16 through 19. There is virtually no change in the patterns introduced by the differences between the measured and ideal values in either the course or clearance radiation patterns.

VSWR measurements were also performed on the Wilcox Log Periodic Dipole antennas used in the array. Table 2 shows the measured VSWR of each antenna.

The initial phasing and performance checks were performed using the ground vehicle and the micro-lab test package. Following these checks the actual flight measurements on the array were begun.

All radiation pattern measurements were made by recording the AGC voltage level of the localizer receiver on a chart recorder with a calibration curve following each series of measurements. This ensures the accuracy of the relative RF data sets. All plots of the measured RF patterns are plotted as dBm versus angle from the center of the antenna array.

Figure 20 is a plot of the course CSB pattern as measured using the above described process. This pattern follows the trends of the calculated pattern with a small amount of non-symmetry between the two sides. (Refer to figure 10 for calculated pattern). The half-power beamwidth on this particular trace is measured to be 5.1°. This also concurs with the 22-8 measured beamwidth. For a comparison between this pattern and that of the 22-8 refer to figure 21.

The measured course SBO radiation pattern for the Redlich array is plotted in figure 22. Again, the points of interest are very near those of the calculated pattern and the measured patterns of the 22-8. The main sidelobes occur at 3° either side of the centerline and have widths similar to those of the 22-8, figure 23. The highest sidelobe levels also are similar, with the highest measured sidelobe on the 22-8 being -22 dB down from the main sidelobes and the Redlich array lobes being -21 dB down within ±45°. This value is considered within measurement tolerances.

As stated earlier, the clearance radiation patterns of the Redlich array and those of the 22-8 array are substantially different. The CSB and SBO radiation patterns of the Redlich array are presented in figures 24 and 25, respectively. The design goal of this portion of the system was to provide maximum clearance levels with no concern of course width settings.

The primary goal of this design effort is to provide a localizer signal with the proper course, course width, and clearances while ensuring that minimum interference is caused due to reflections. The CDI plot of figure 26 shows the measured CDI pattern for the combined array. With the proper power levels, minimum clearance levels, and path widths are ensured.

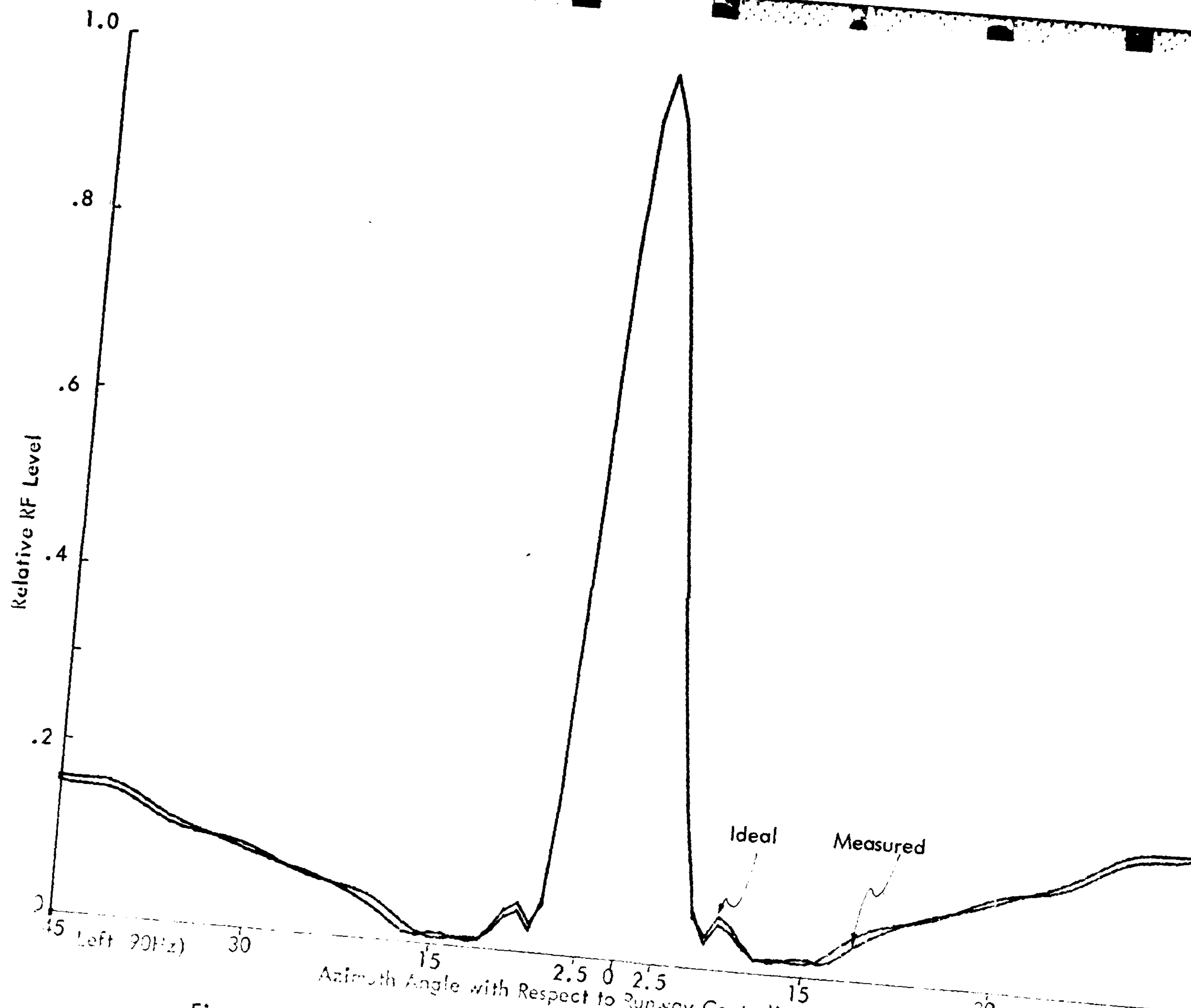
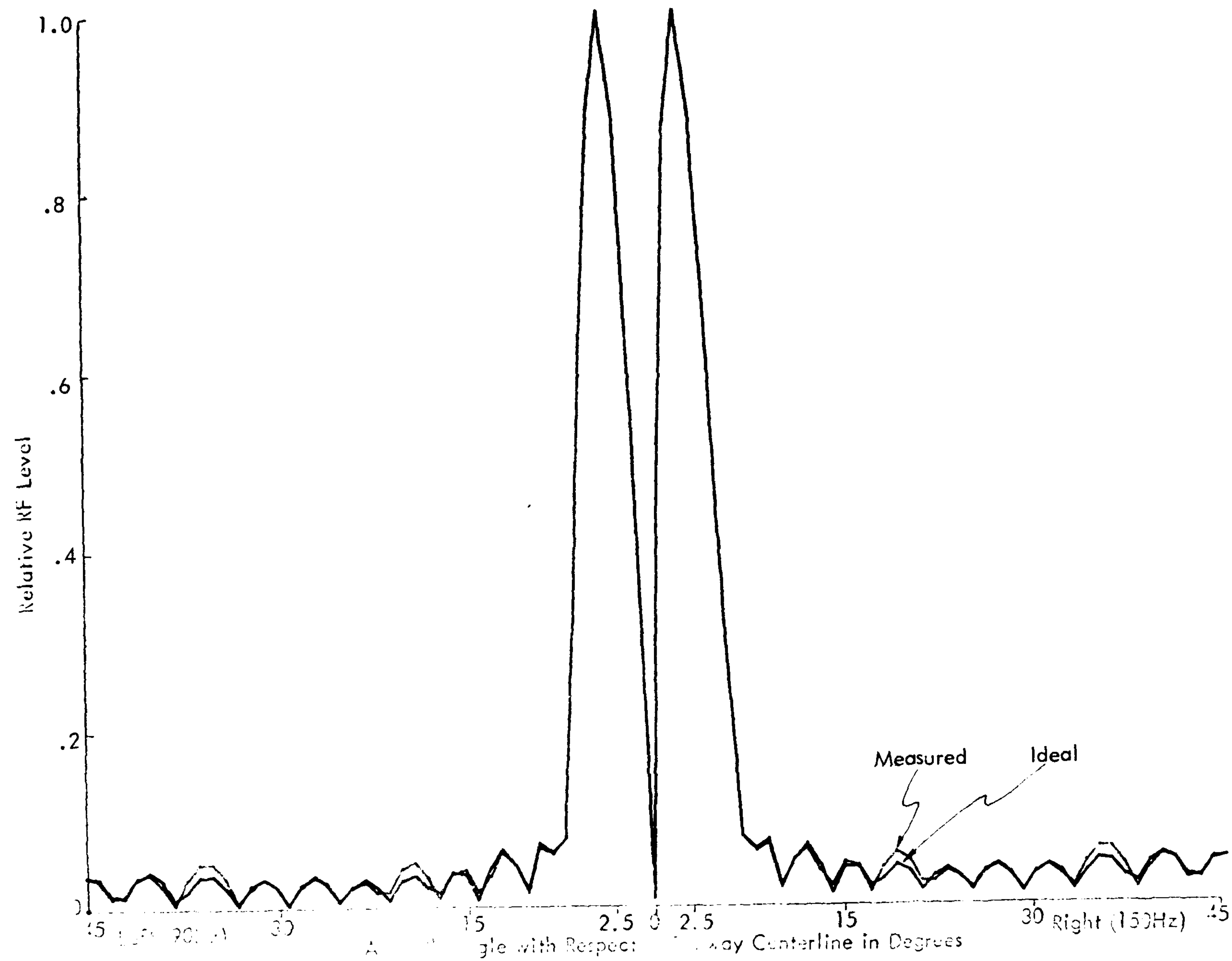


Figure 16. Comparison of Redlich Course CSB Patterns Using Ideal and Measured Currents.



igure 17 om ots of Kedlich Pa terns Using Ideal and Measured Currents.

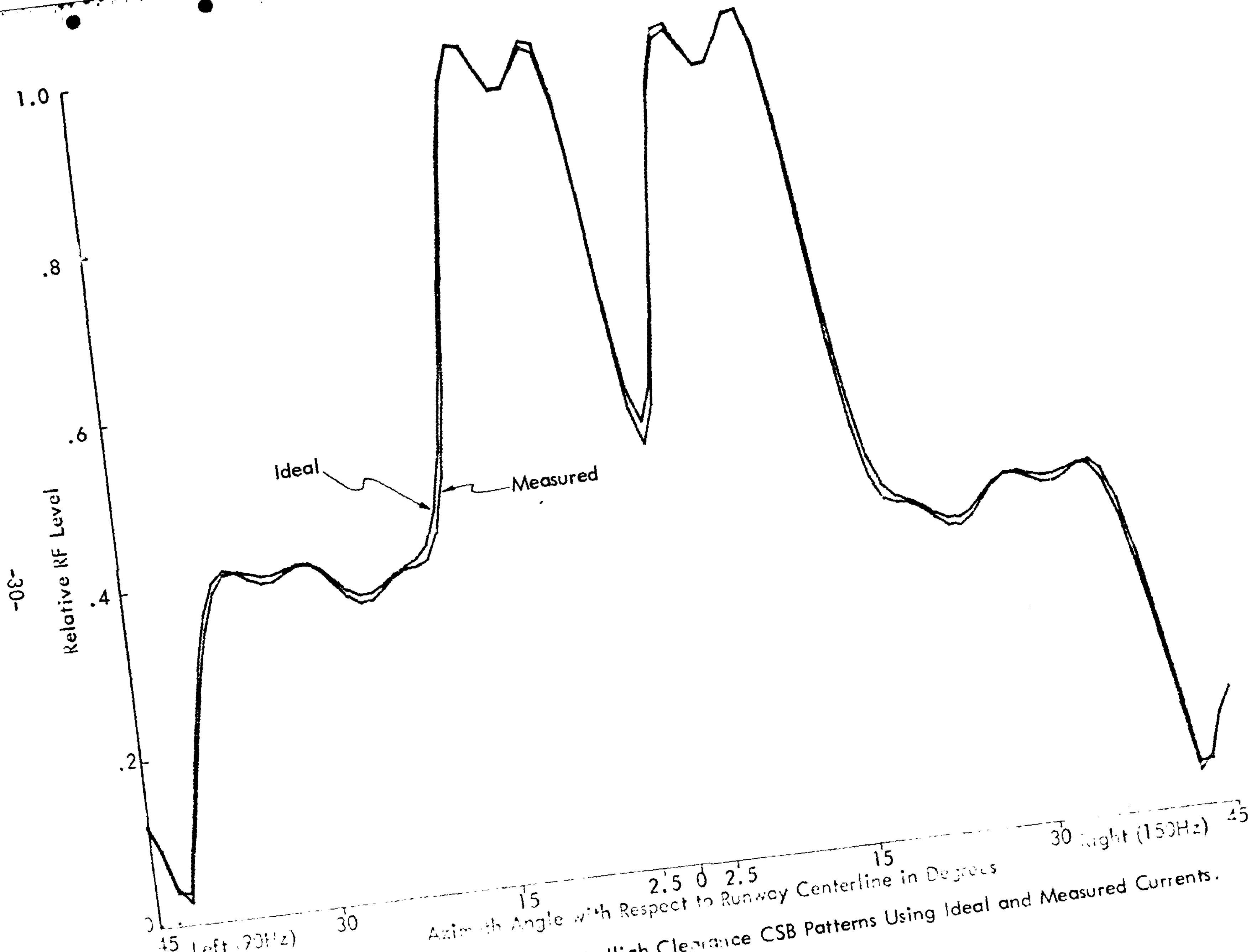


Figure 18. Comparison of the Redlich Clearance CSB Patterns Using Ideal and Measured Currents.

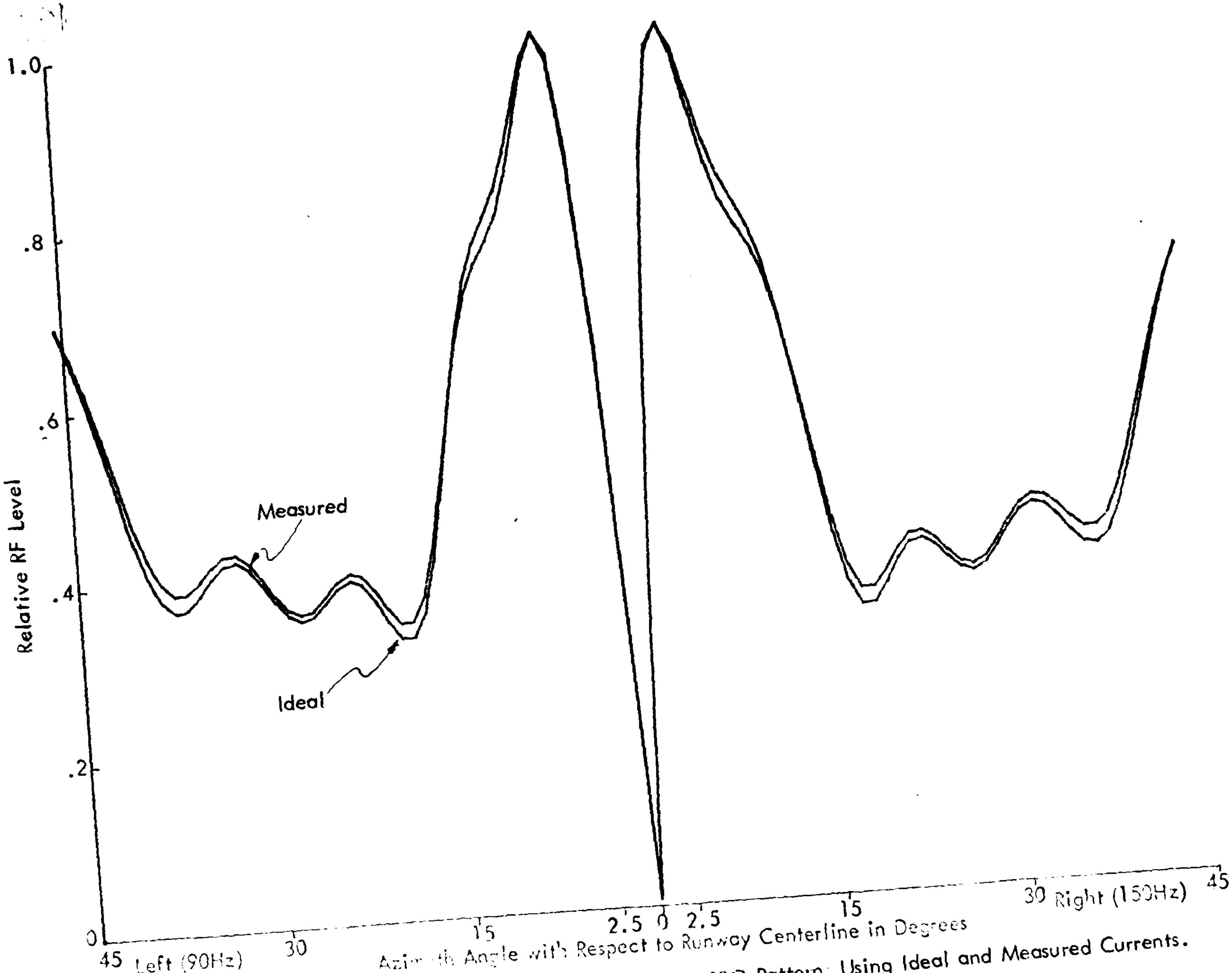


Figure 19. Comparison of Redlich Clearance SBO Patterns Using Ideal and Measured Currents.

Antenna	VSWR
1L	1.01
2L	1.06
3L	1.06
4L	1.02
5L	1.02
6L	1.01
7L	1.02
1R	1.02
2R	1.01
3R	1.02
4R	1.02
5R	1.01
6R	1.01
7R	1.01

Table 2. VSWR Checks of LPD Antennas Used in Redlich Array.

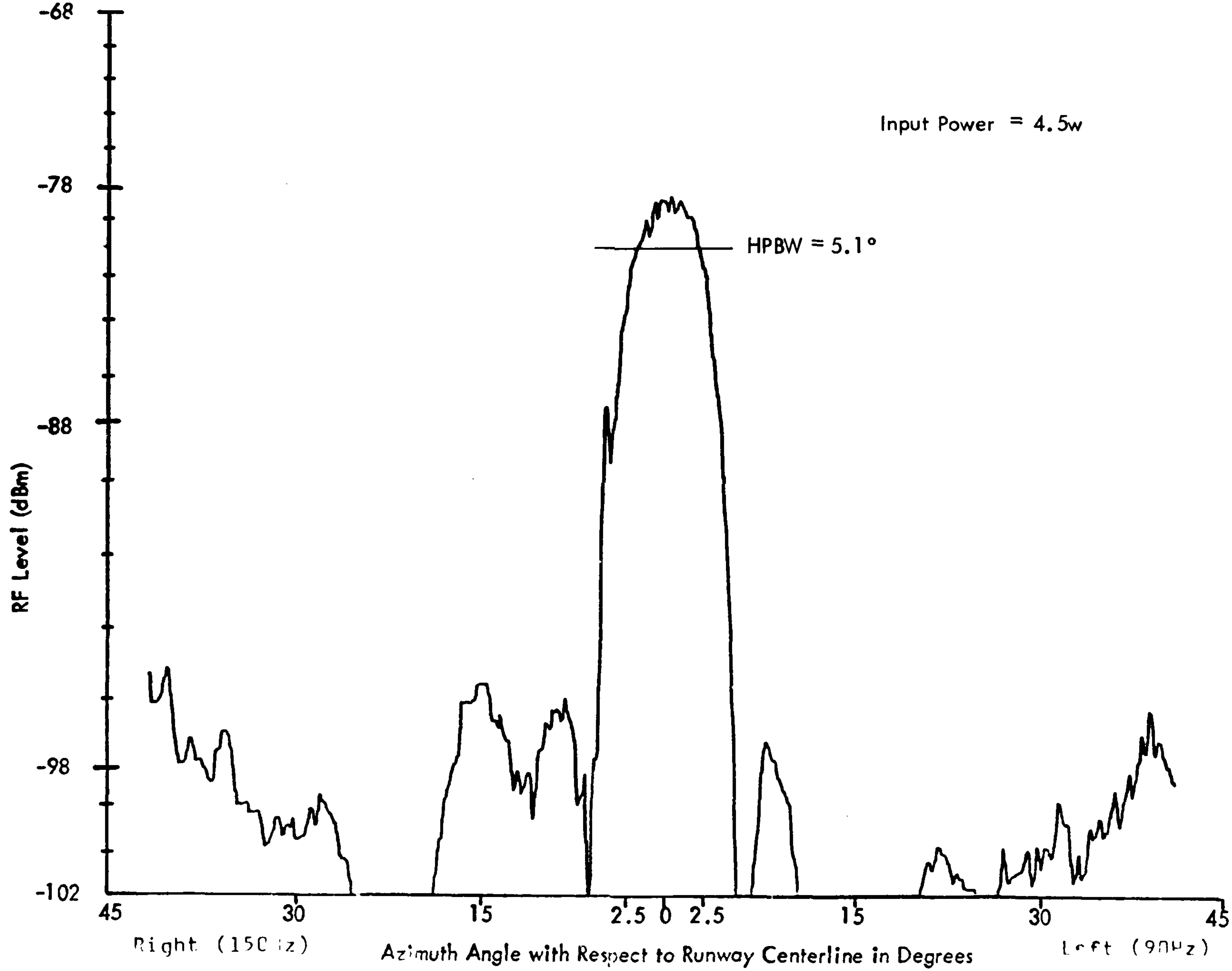
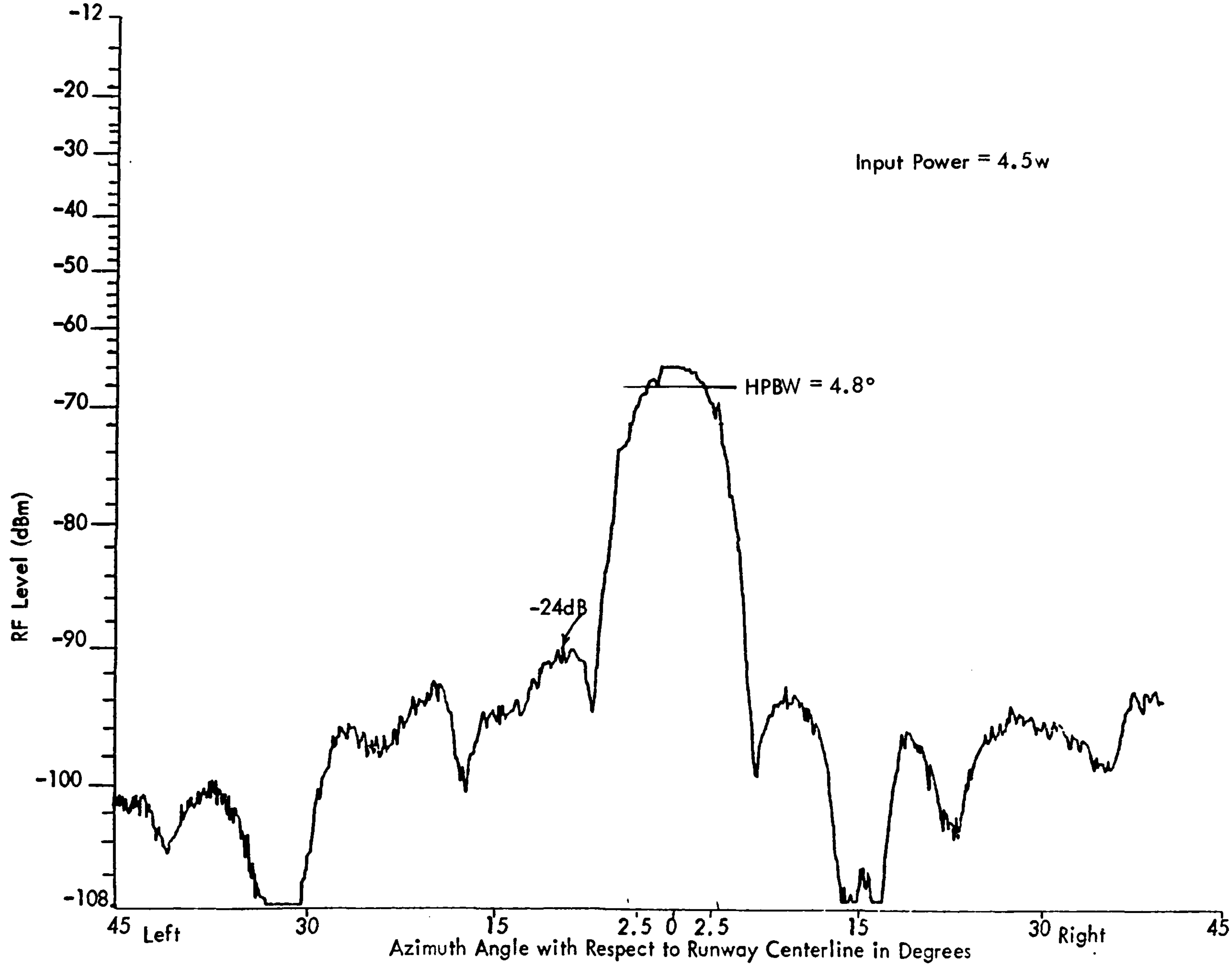


Figure 20. Measured Course CSB Radiation Pattern for the Redlich Array.



'gure 21 Measured Course CSB Radiation Pattern for the 22-8 Localizer Array.

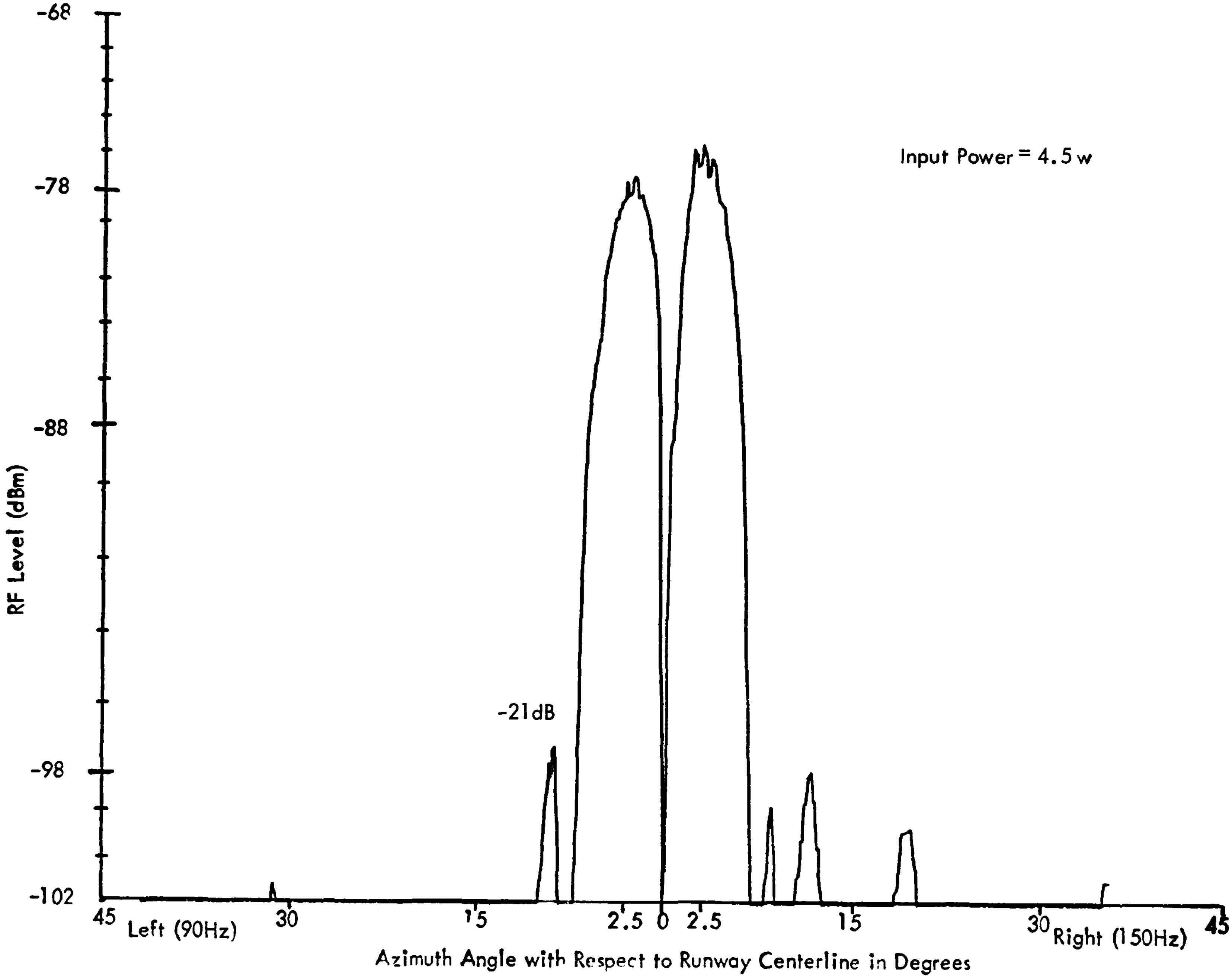


Figure [illegible] Measured Course [illegible] Pattern for the Redlich Array.

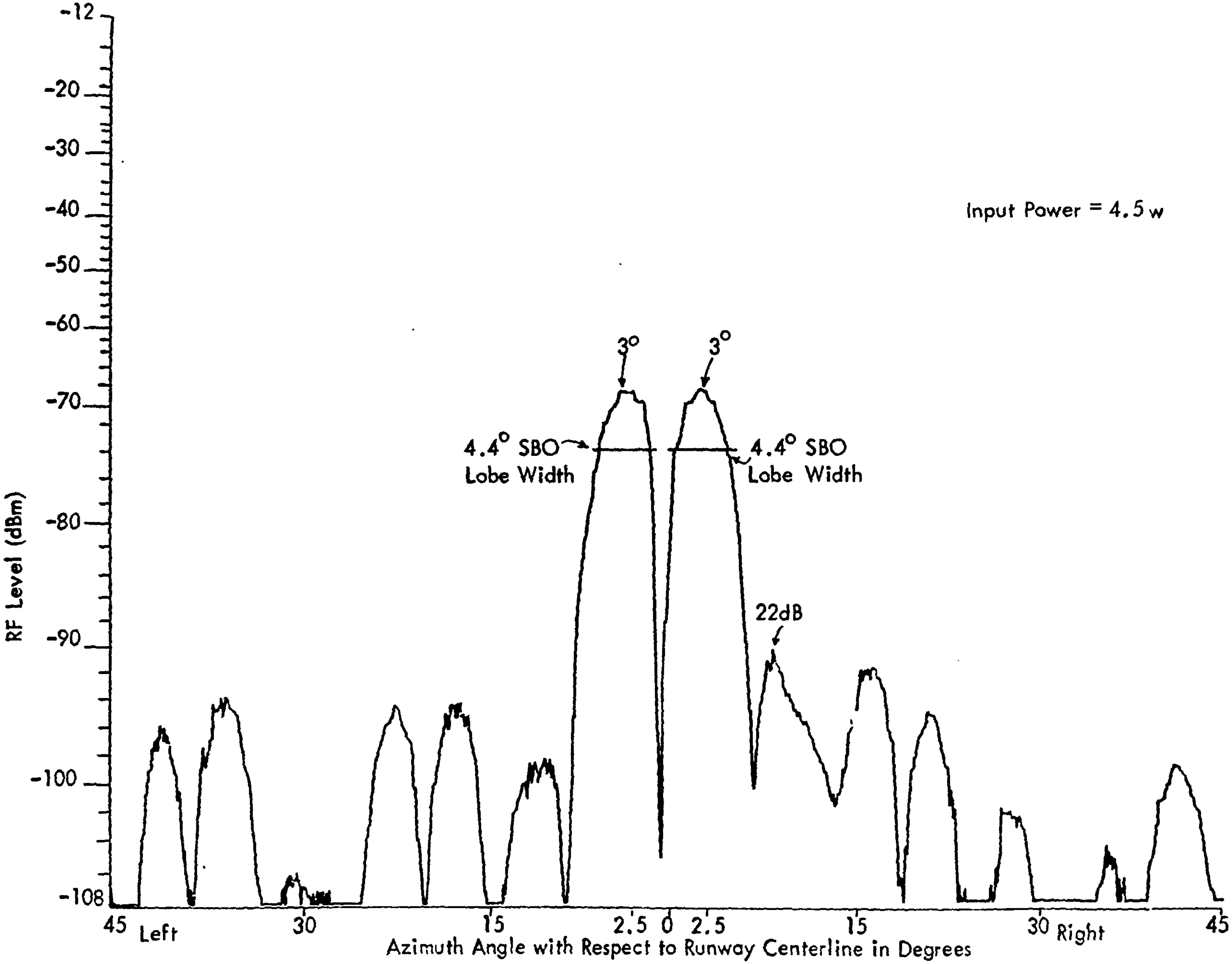


Fig. Measured Course SBO Radiation Pattern for the 22-8 Localizer Array

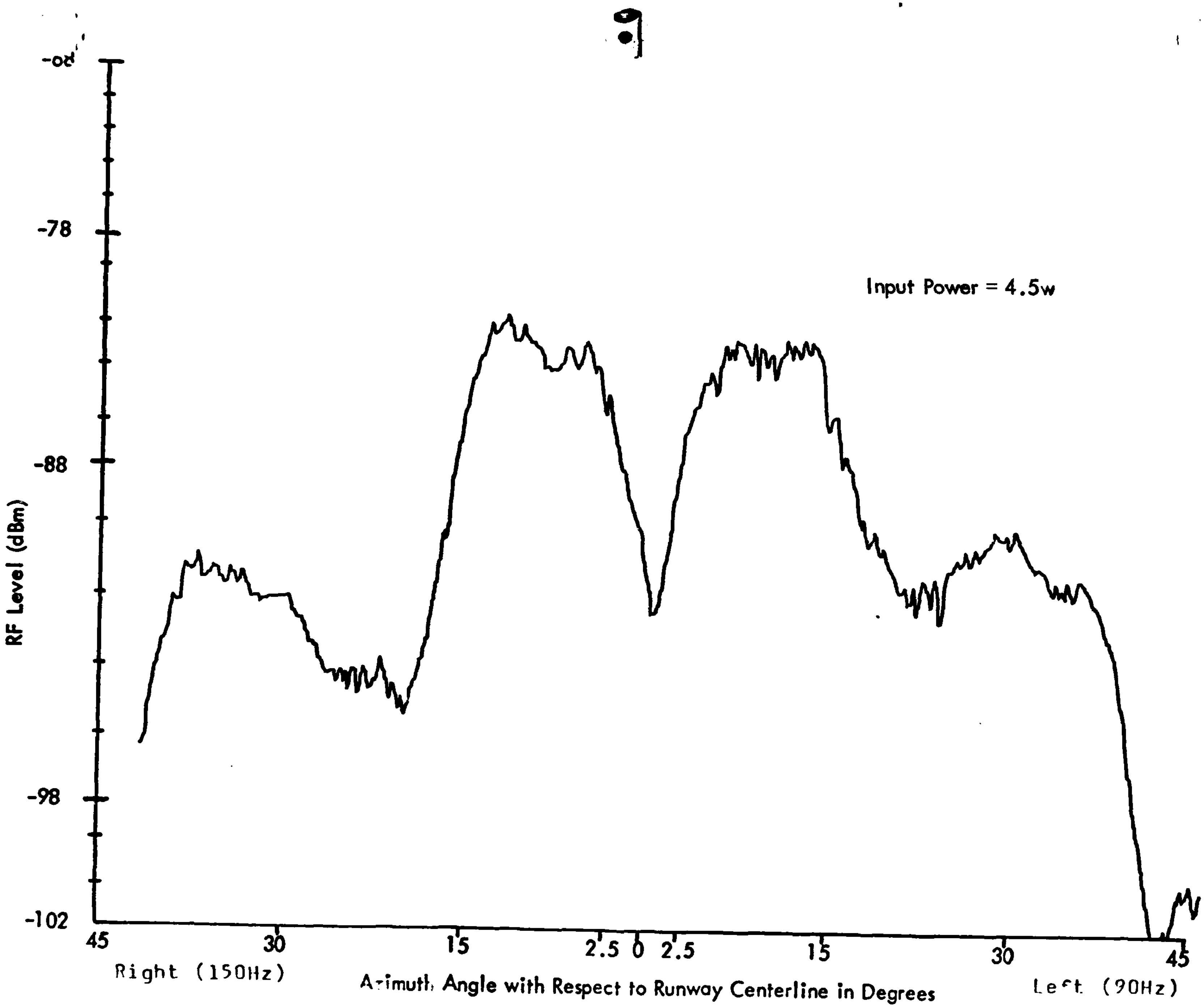
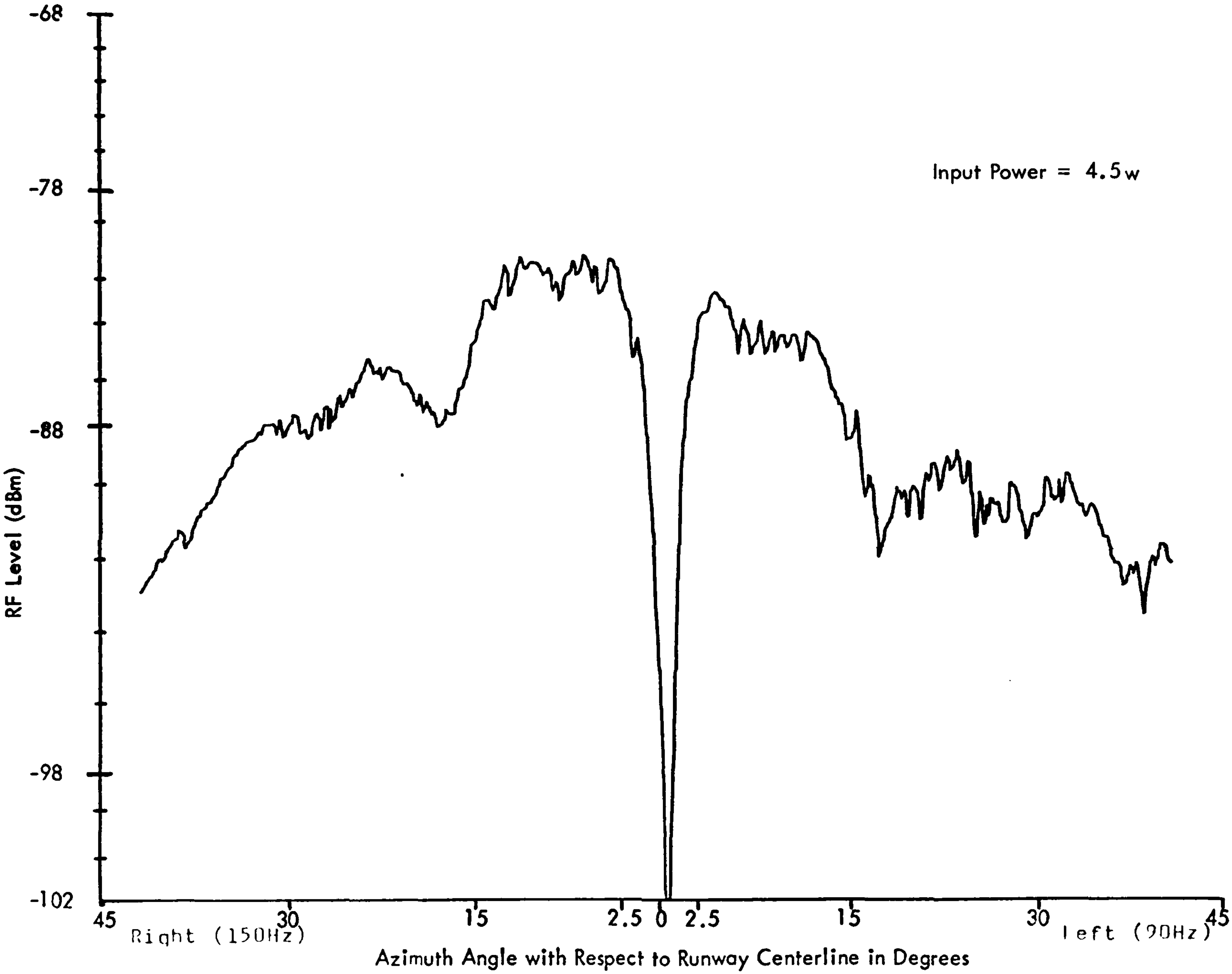


Figure 24. Measured Clearance CSB Radiation Pattern for the Redlich Array.



Fi ure 25. Measured Clearance SBO Radiation Pattern for the Redlich Array.

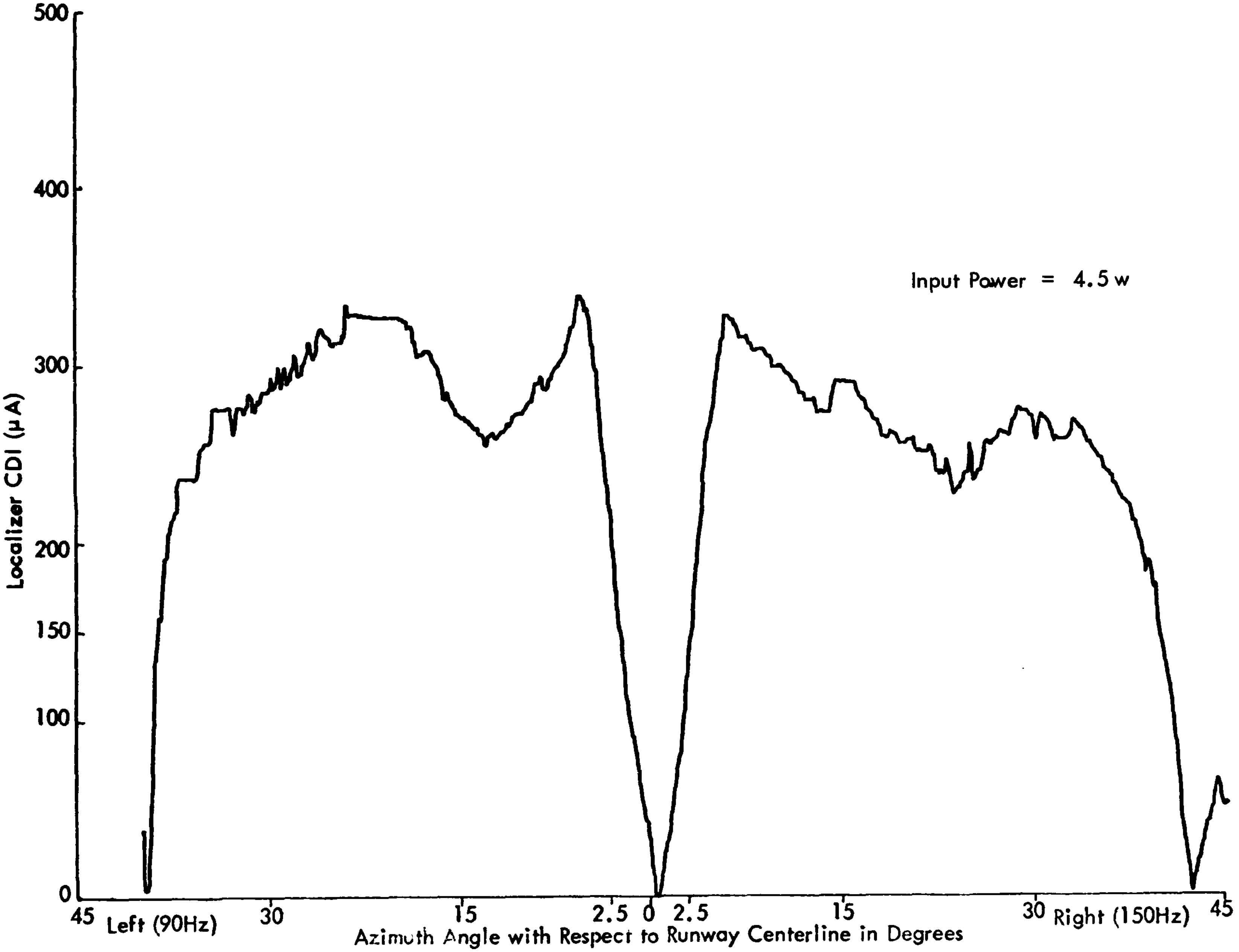


Figure 26. Measured CDI Pattern for the Redlich 14 Element Two Frequency Localizer.

SUMMARY AND CONCLUSIONS.

The calculated and preliminary experimental evaluations of the Redlich localizer array have resulted in the following conclusions.

1. The calculated patterns for the Redlich 14-element, two-frequency localizer and those of the Alford 22-8 two-frequency localizer indicate that array performance for the two should be very similar.

2. The performance of the Redlich 14-element, two-frequency localizer is similar to that of the 22-8 at a frequency of 111.9 MHz between ±45° azimuth from summary centerline. Measured beamwidth, sideband lobes and sidelobe levels are all within the prescribed values established by the 22-8.

SECOND SERIES OF MEASUREMENTS TO EVALUATE THE REDLICH WIDE-APERTURE ARRAY

A second series of measurements to evaluate the performance of the Redlich 14-element, two-frequency localizer was accomplished at the Ohio University ILS test site at the Tamiami Airport, Miami, Florida during the period July 27 to July 31, 1981.

The purposes of these additional measurements are to resolve some asymmetrical patterns obtained of CDI and flag current versus azimuth, to extend sideband RF patterns in azimuth to ±90° from the ±45°obtained earlier, to obtain documentation on the structure of the path along the approach to landing and over the runway, to obtain additional field strength data, and to develop a technique for probing the Wilcox log-periodic dipole (LPD) antennas. Additional ground runs were made using a van with the Ohio University microlab receiving/recording setup.

REQUIRED DATA.

In order to establish a somewhat rigorous procedure of data collection for the evaluation of the Redlich array and ultimately the Wilcox array, a listing of critical records was developed. See table 3. The goal is that once these records are acquired the fundamental data for evaluation and decision making have been obtained.

Condition	A/C Track	Variables Recorded	Parameters	Crucial Items
Normal, 2-freq. operation	±35° arc	AGC,Flag, CDI	Frequency 111.9 MHz ***** ***** Course width = 3.0° = max 7.2	CDI Clearance level AGC Signal level
Course only, CSB into SBO port	±90° arc	AGC	111.9 MHz ____ ____	Sidelobe level
Course only CSB only	±10° arc	AGC	111.9 MHz ____ ____	1/2 power beam width
Normal 2-freq. operation	±10 10-35	AGC	111.9 MHz ____ ____	Usable dis- tance (relative based on TMB power in)
Normal 2-freq. operation	Approach	CDI Diff.Amp Theodolite Flag	111.9 MHz	Structure roughness

Table 3. List of Measurements Required for Evaluation of the Redlich Localizer.

DATA COLLECTION.

The data considered especially pertinent for documentation purposes is that recorded during flight. Van runs were made in the near field area and are used only for preliminary setup purposes. The flight data, all for a nominal carrier frequency of 111.9 MHz were collected using the Ohio University Mark III minilab flown in a Model 36 Beechcraft. A reference was accomplished using a Warren Knight WK-83 radio telemetering theodolite located 20 feet in front of the array on the runway centerline extended. A Reaction Instruments Model transmitter provided uplink telemetry information. Typically, the data showing the azimuth patterns of CDI, RF distribution and flag current were made with a flight track following a circular arc, radius 5 miles, 1300 feet AGL. Approximately 10 hours of flight time were used to acquire 80 records.

Figure 27 is a photograph of the 14 log periodic dipoles forming the Redlich array at the Tamiami site. This is to the northwest with the array serving runway 9L.

Figures 28 through 36 show the digitized chart recordings of the data collected using table 3 as a guide. Figure 28 is the normal, two-frequency system CDI pattern with a course width of 3.0°. The track flown was a ±35° arc. The pattern is slightly asymmetrical, but the minimum clearance levels of 175 and 150 microamperes as prescribed in, FAA Handbook, 8200.1, Section 217.5 (11) the U. S. Flight Inspection Manual, are met with no difficulty.

In figure 29 the CDI pattern for a course width of 7.2° is shown. Again, the clearance levels are well above the 135 microampere level required in the ±35° area. The asymmetrical nature of these two records will be discussed later.

Recordings of the flag currents for the normal two-frequency runs are shown in figures 30 and 31. The minimum flag current level of 240 microamperes is available throughout the ±35° localizer clearance area. Again, there is a lack of symmetry in the flag currents as was recorded in the CDI patterns. Experience indicates that an exceptionally high flag current level is present in the 5° to 25° region on the south (150 Hz) side of the array. This high flag current could possibly be an indication of some anomaly in the system even though the minimum required flag current levels are met.

The AGC recording of figure 32 is presented in order to demonstrate that sufficient signal levels are present along this track (5 nautical miles, 1300 feet AGL) for a usable signal. In addition, note that this signal is substantially more symmetrical than either the CDI or the flag current measurements. This would indicate that anomaly exists in the sideband portion of the antenna array since the AGC measurement here is a composite of the carrier portions of the course and clearance arrays.

Of major concern in a Category III quality localizer system is the magnitude of course bends or roughness introduced by reflections from

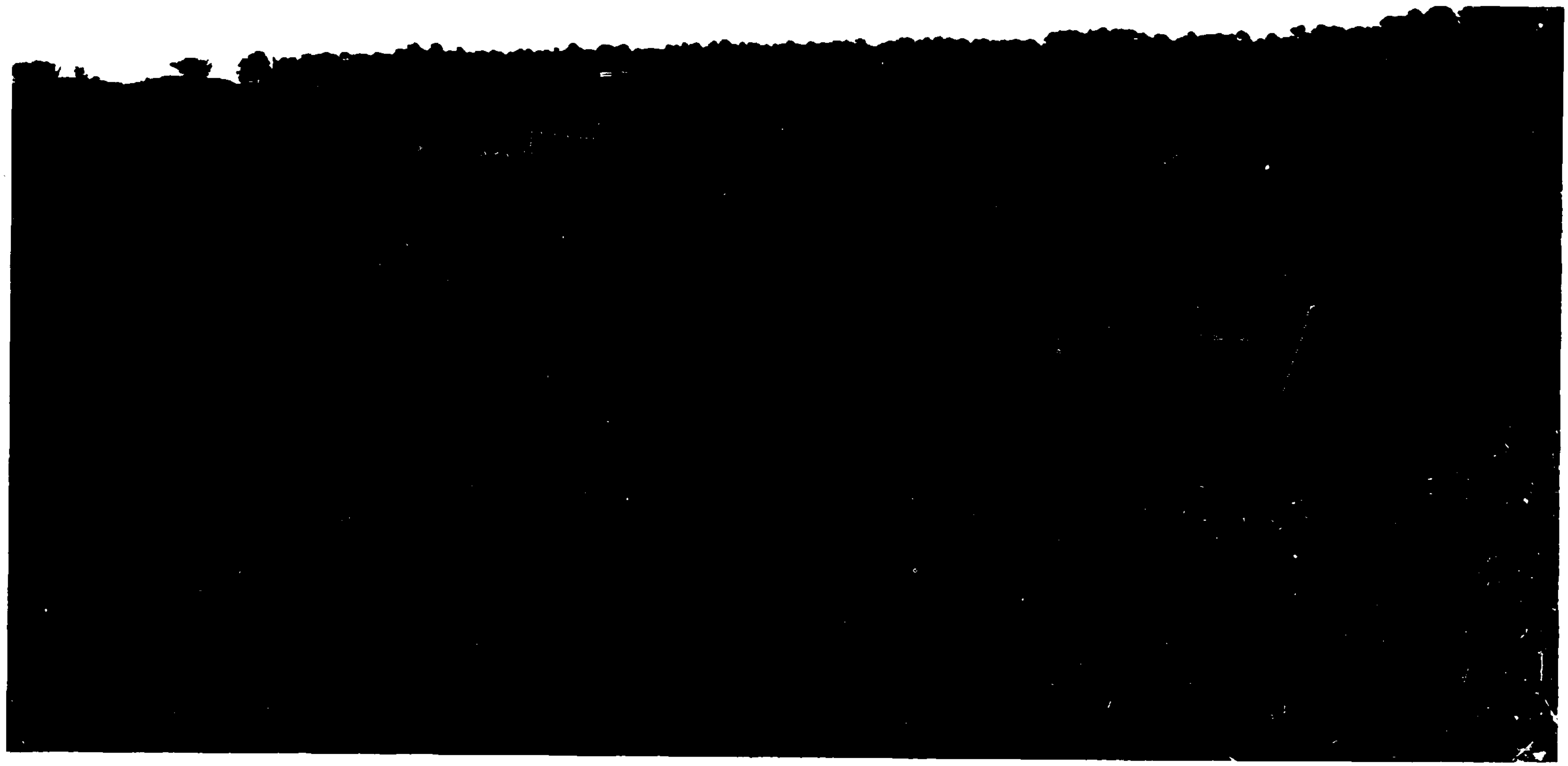
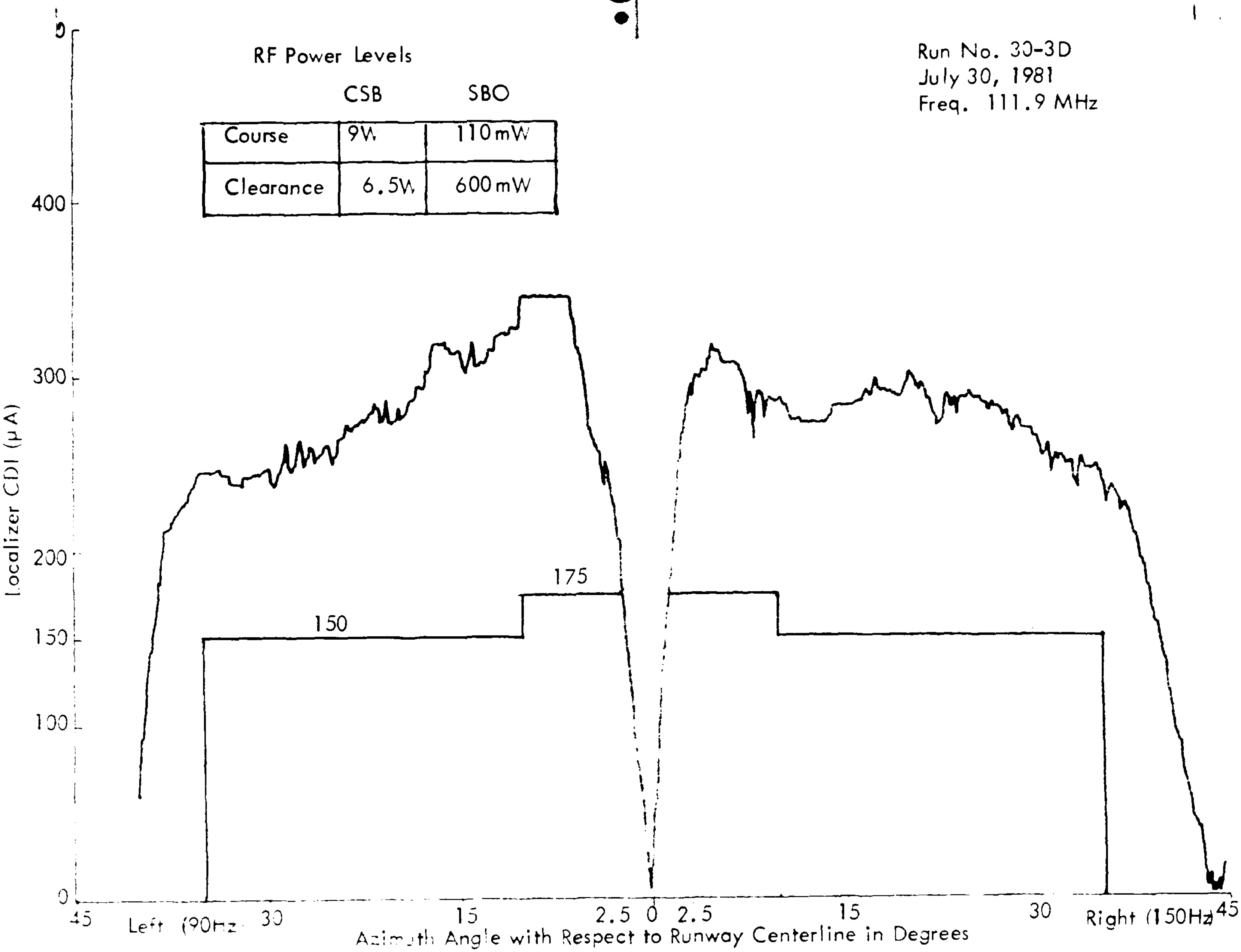
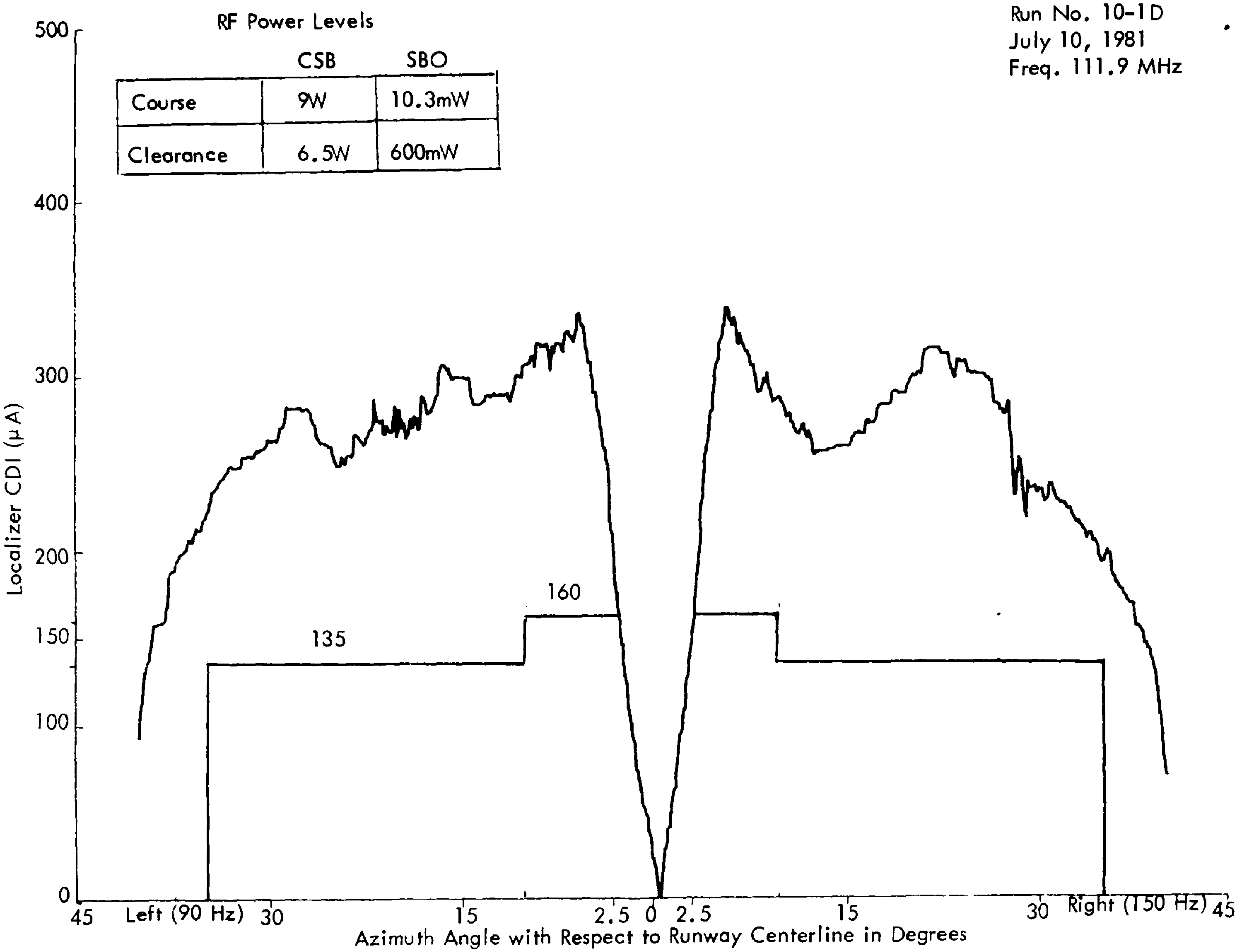


Figure 27. View of the Redlich 14-Element Localizer Installed on RW 9L at the Tamiami Airport.



Fi ure 28. M sured Pattern for the Red Localizer with a Course Width of 3.0°. This is the re tan ne two-frequenc ion with the course and clearance arrays. The to ranc icated by the b str ct res prescribed by the U.S. Flight Inspec- c ion 217.5 (II).



	CSB	SBO
Course	9W	10.3mW
Clearance	6.5W	600mW

Figure 29. Measured CDI Pattern for the Redlich 2-Frequency Localizer Array with a Course Width ≈7.2°. Tolerances are shown by the boxes.

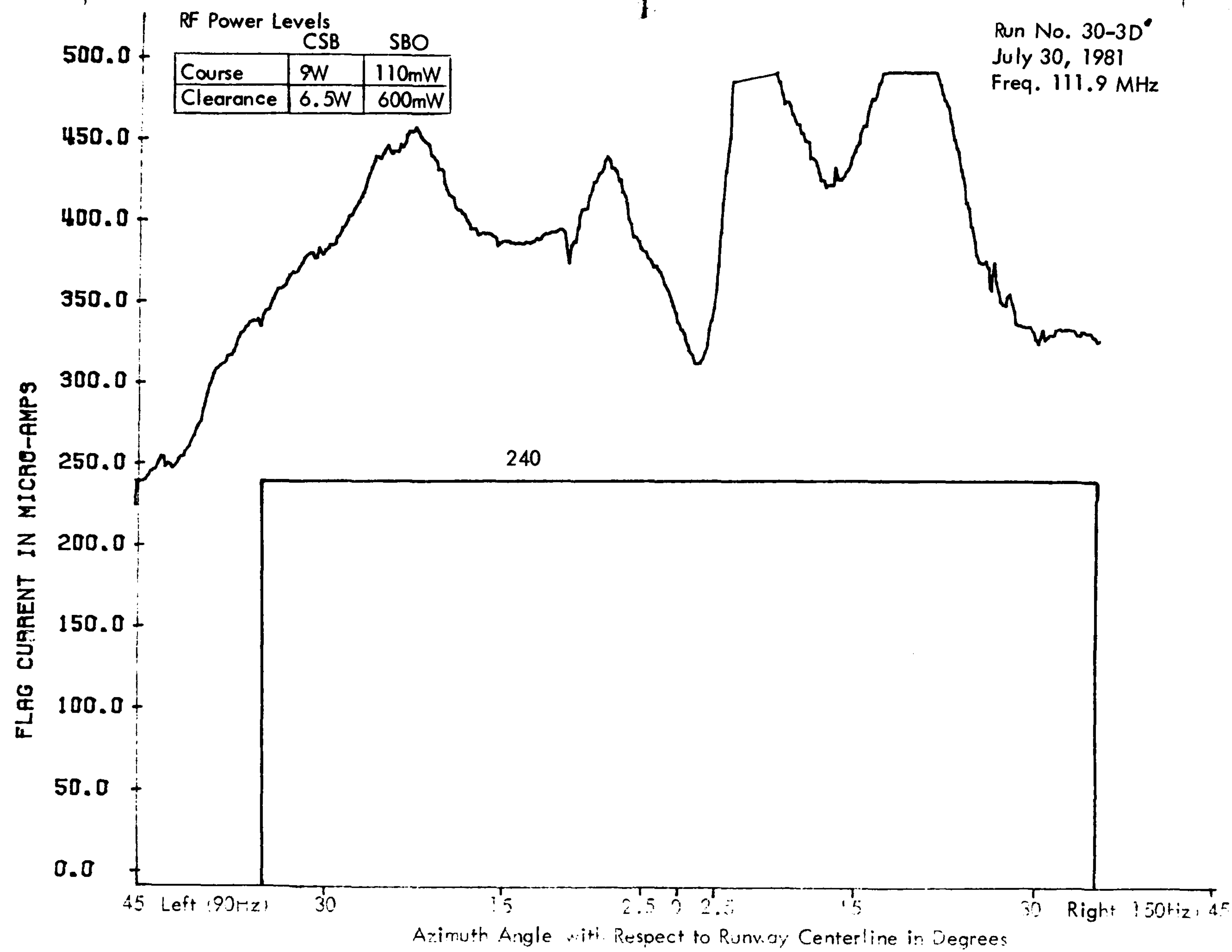


Fig 30. Me red ent Levels for the Redlich 2-Frequency Localizer for a Course Width of 3.0°. Thi s for th ined array. To shown by the box. This recording corresponds to Fig

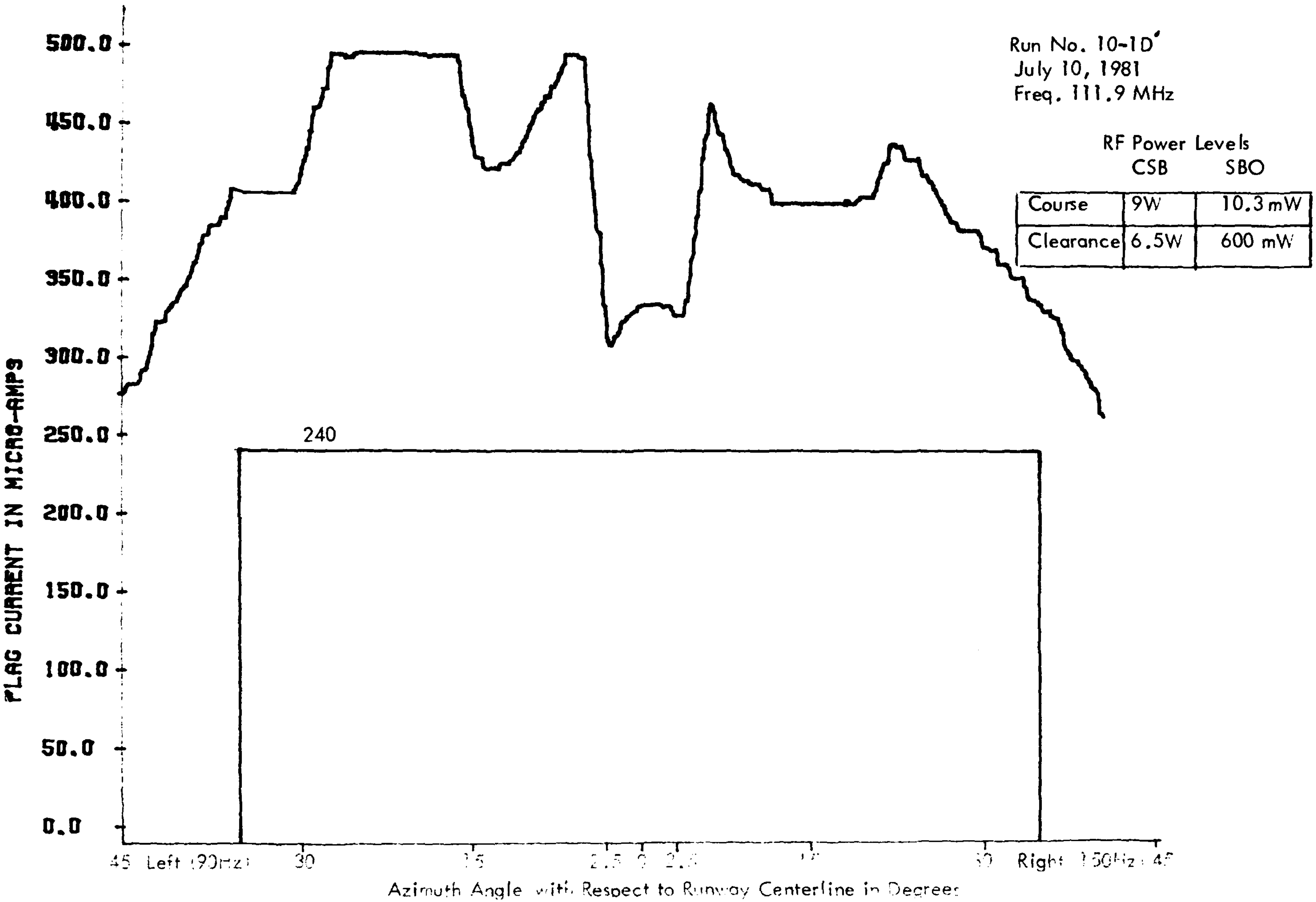
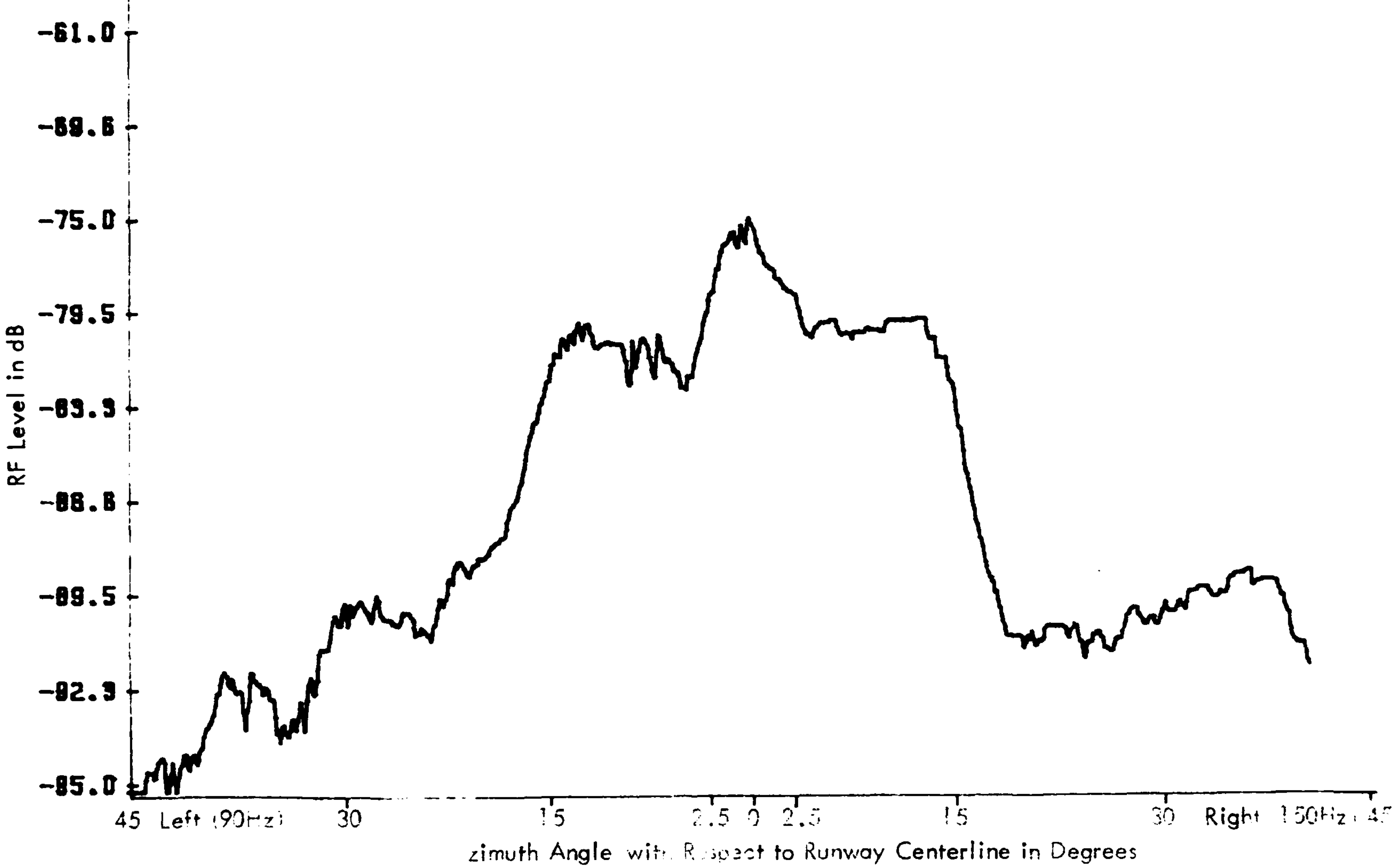


Figure 31. Measured Flag Currents for the Redlich Localizer for a Course Width of 7.2° Combined Array. Tolerances are shown by the box. This recording corresponds to Figure 29.

RF Power Levels

	CSB	SBO
Course	9W	110mW
Clearance	6.5W	600mW

Run No. 30-3D
July 30, 1981
Freq. 111.9MHz



AGC Recording of Normal Two-Frequency System: Redlich Localizer.

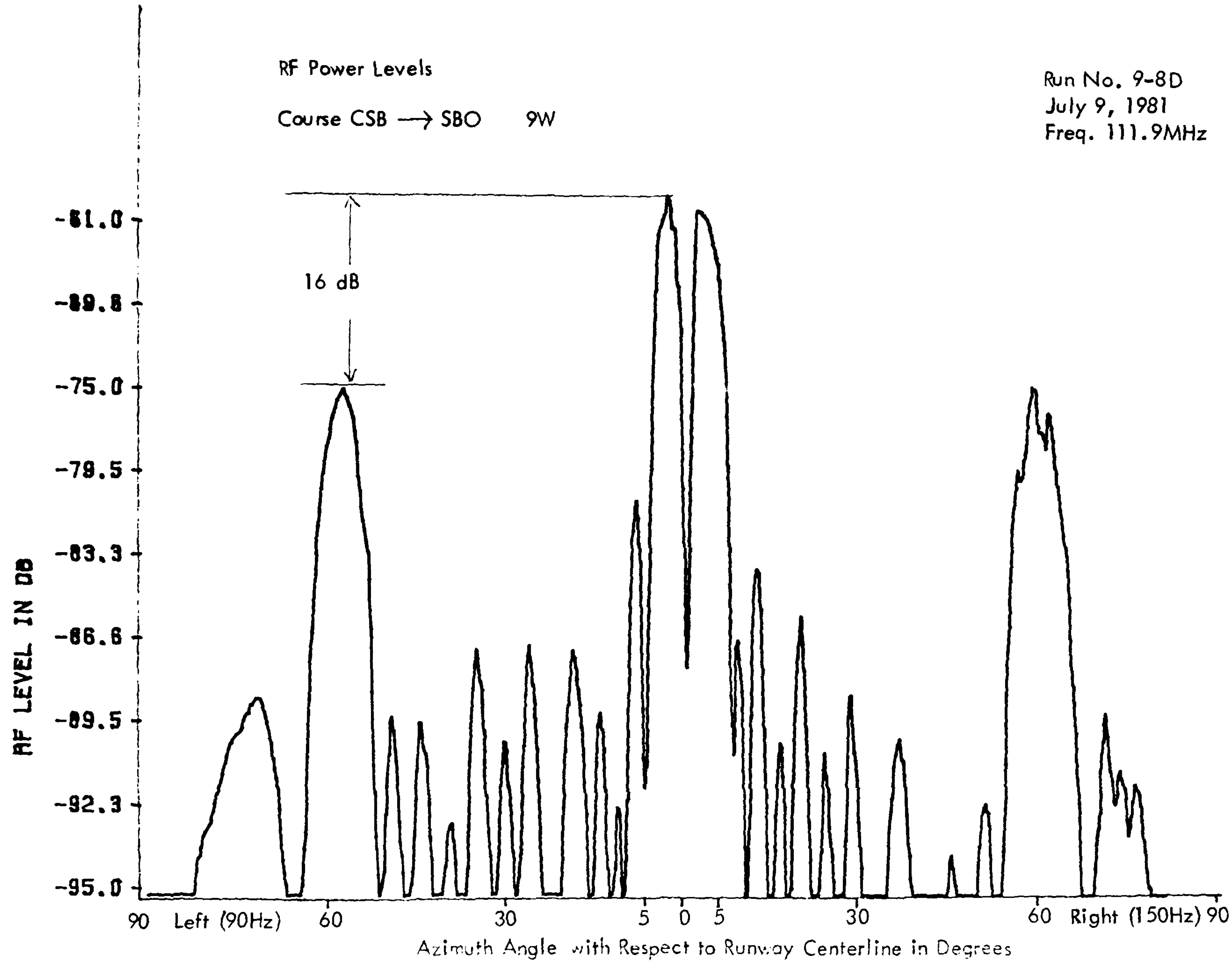


Fig re 33. Measured Course SBO Pattern for the Redlich Localizer.

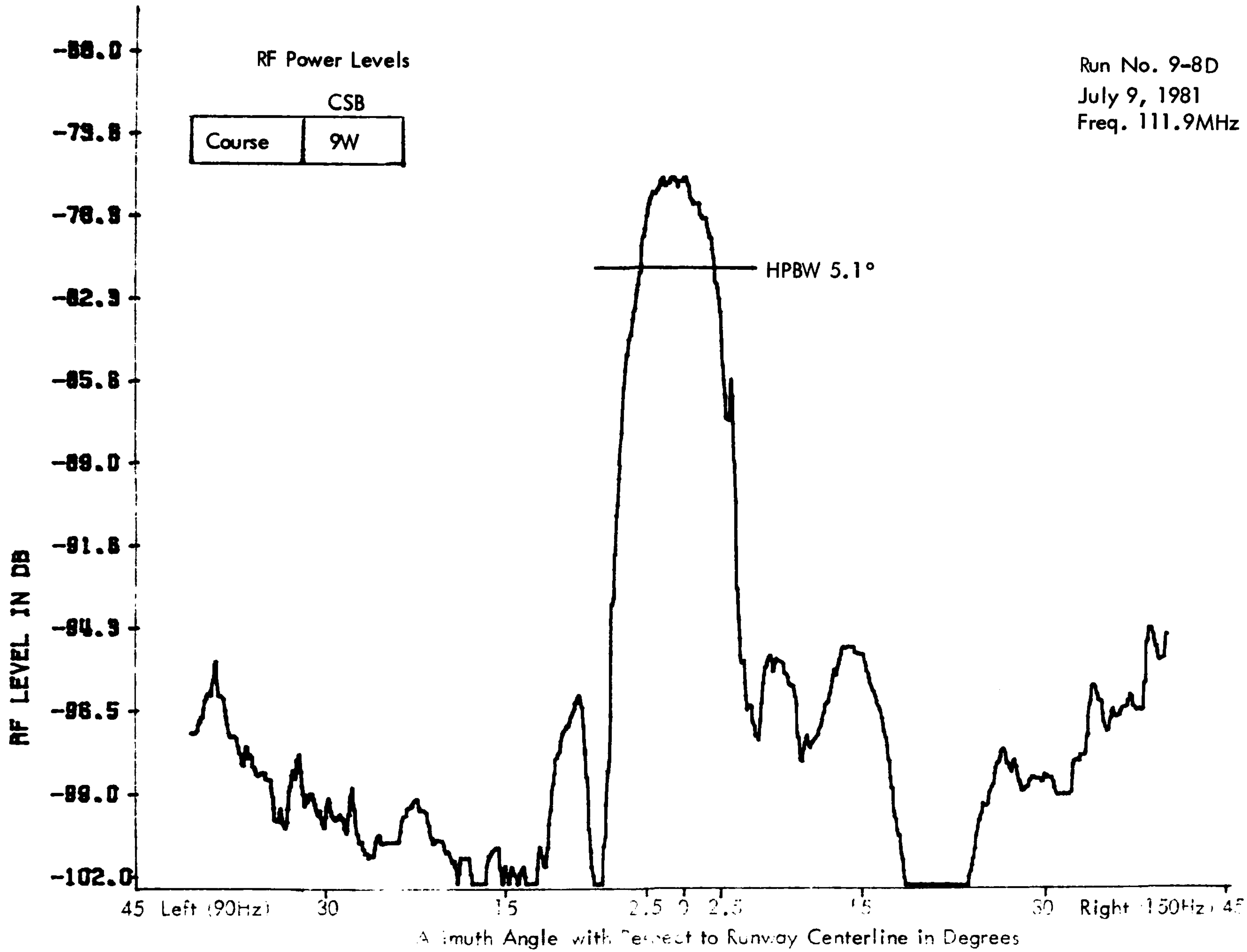


Figure 3 Mc[illegible] urse CSB Show[illegible] Beamwidth to be 5.1° for the Redlich Localizer Array.

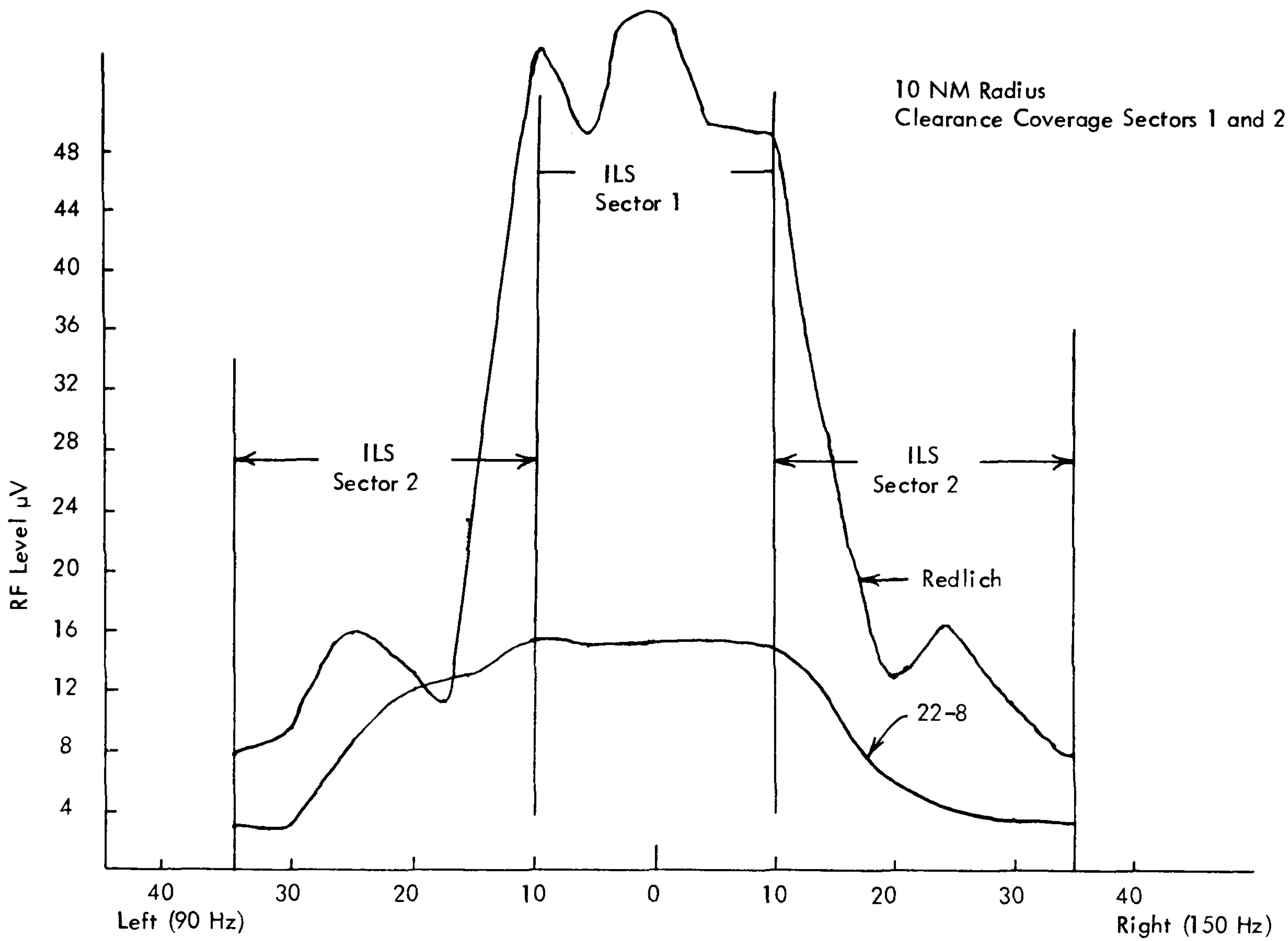


Figure 35. Clearance Coverage Area for the Redlich and 22-8 Localizer Arrays. Levels are normalized to a nominal input power of 7 watts.

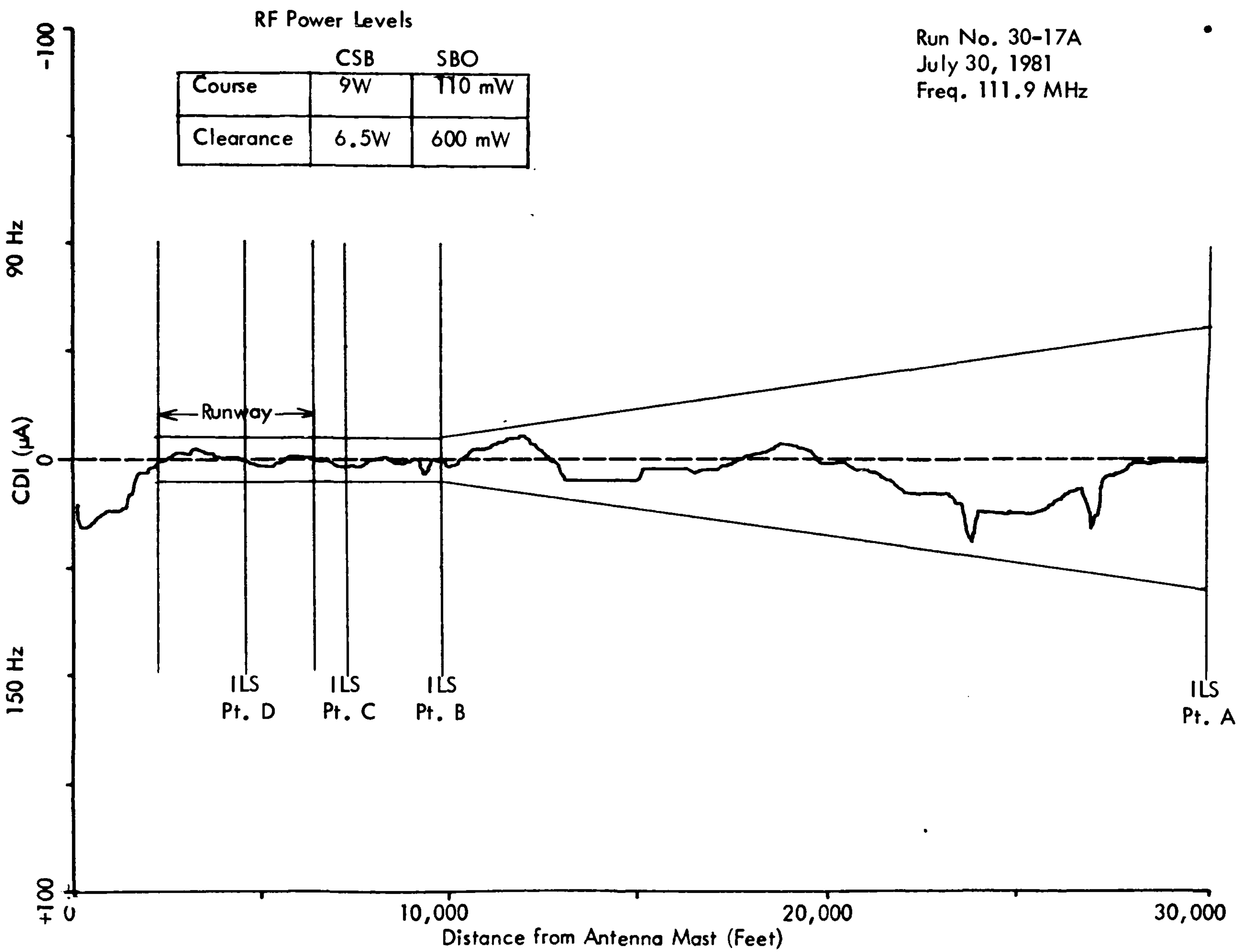


Figure 36. Measured CDI of Redlich Localizer Course Showing Relation to Tolerance Bounds. This was made without a theodolite reference and represents a worst case course noise plus that introduced by the aircraft and pilot. In spite of this, the course is within CAT III limits.

structures in the array area. The most influential portion of the localizer system in the creation of course bends is the sidebands only or SBO pattern. The SBO pattern for the Redlich array is shown in figure 33. This pattern was measured by feeding 4.5 watts of carrier power into the SBO port on the course distribution unit. The measurement was then made from +90° to -90°. The sidelobe levels are at least -22 dB from the main lobes except at approximately ±60 degrees from the runway centerline. At these points the relative power levels are only -16 dB from the main lobes using the Wilcox LPD antenna.

Also of interest in this type of localizer is the course carrier one-half power beamwidth. An arc from approximately -10° to +10° was used to measure this parameter. The recording of figure 34 shows the measured CSB pattern used to determine the beamwidth for the Redlich array. The measured beamwidth shown here is 5.1°. This value agrees within measurement tolerances with that obtained from the 22-8 localizer system.

Usable distance measurements were also recorded. This set of measurements is presented in table 4 and figure 35. The power levels measured at the input of the distribution unit are also included in table 4. The results of these measurements are also compared against those of the 22-8 system in table 4 and figure 34. With the available input power, the RF level in the clearance coverage area of the Redlich array is above that of the 22-8 except for the area between 16° and 19° on the left side of the array.

The structure and alignment of the course were measured and digitized. A record of these measurements is shown in figure 36. The trace of figure 36 is the digitized raw CDI. A problem in the telemetry transmitting equipment precluded the collection of valid RTT data; therefore, only the CDI trace is presented here. This trace is presented to show roughness only.

DISCUSSION.

As stated earlier, an asymmetrical condition in the CDI and flag current recordings with the principal disparity occurring from 5° to 25° in azimuth on the south (150 Hz) side of the array. Flag readings were as much as 55 microamperes greater in this area. Flight inspection tolerance values were all met; nevertheless, it was of interest to determine whether an anomaly in the array existed which might cause this problem.

Probing of the antennas was believed to be the most conclusive method of locating a possible anomaly. A probing technique is not firmly established for the LPD type antenna and attempts at probing led to inconclusive results. This is thought to be due to the high (super) gain properties of the LPD type antenna. In-line measurements and measurements of the signals from the monitor output ports of the antennas indicated that potentially mutual coupling was affecting the clearance signals associated with the number 2 right and left antennas. It was determined that the most accurate method of ascertaining this would be to locate the Portable ILS

Parameter	8200.1 (CHG 32)	Redlich Measured Value	22-8 Measured Value
Usable Distance	5μV @ 18 NM	31.6μV	18μV
Coverage	5μV @ 10 NM Sectors 1 and 2	See figure 35	See figure 35

Table 4. Comparison of Usable Distance of the Redlich and 22-8 Arrays to the U.S. Standard Flight Inspection Manual.

Power Input at Distribution Unit Course = 4.5 Watts
Redlich Localizer Clearance = 2.5 Watts
Frequency = 111.9 MHz

Power Input at Distribution Unit Course = 4.5 Watts
22-8 Localizer Clearance = 4.5 Watts
Frequency = 111.9 MHz

Receiver (PIR) antenna in front of each element in question and take readings using the vector voltmeter. This field set-up is shown in figure 37. A normalized current value of .036 with a phase of 0° (referenced to antenna number 1) was prescribed and a current of .190 with a phase of -114° was measured.

Although measurements strongly suggested that significant modification of the desired voltage was produced. The values shown in table 5 show that as the drive of neighboring antennas was eliminated the value of the voltage read for the number 2 elements returned essentially to the design values. Because the design currents for the number 2 elements is much lower (-26 dB) from its inboard neighbor, the coupling effect can be expected to have a greater percentage effect on the phase and a proportionally larger effect of the magnitude.

Calculations and measurements were made to determine whether symmetry would be improved if the clearance CSB (carrier sideband) excitation of the number 2 elements were removed and finally would symmetry be restored if the total excitation to the number 2 elements were reduced to zero by placing dummy loads on all ports. In addition, the antenna feedlines were reversed at the distribution units to determine whether or not an anomaly exists within the antennas or feedlines.

First, the clearance CSB signal of the number 2 antenna pair was removed. It was hoped that if the measurement noted by the in-line and monitor port measurements was a factor in the asymmetrical flag condition, then the system should become symmetrical with the removal of current from this pair. Figure 38 shows the measured flag current with the clearance CSB signal removed and all open ports dummy loaded. The flag current changed dramatically, but it does not become symmetrical. Also, note in figure 39 that the combined AGC pattern becomes less symmetrical than the original configuration.

Next, all signals were removed from the number 2 pair by loading the output ports on the distribution unit. Also the input and monitor ports of the two antennas were loaded. This test resulted in the flag currents recorded in figure 40. Again the asymmetrical condition exists and in addition the AGC recording of figure 41 becomes severely asymmetrical.

These tests indicate that if mutual coupling in the number 2 pair exists it does not seem to be a major factor in the asymmetrical flag conditions noted in figures 30 and 31.

The antenna feedlines were then reversed to ascertain where the anomaly might exist. The flag current again was slightly altered in the area between ±5° in azimuth, but basically the same trends exist in the data. See figure 42. This would indicate that the anomaly causing the asymmetrical CDI and flag conditions exists within the antennas, feedlines, or that it is some environmental factor in the area.

The azimuth sector where the greatest variation in the CDI value and flag current levels are occurring is in the clearance portion of the

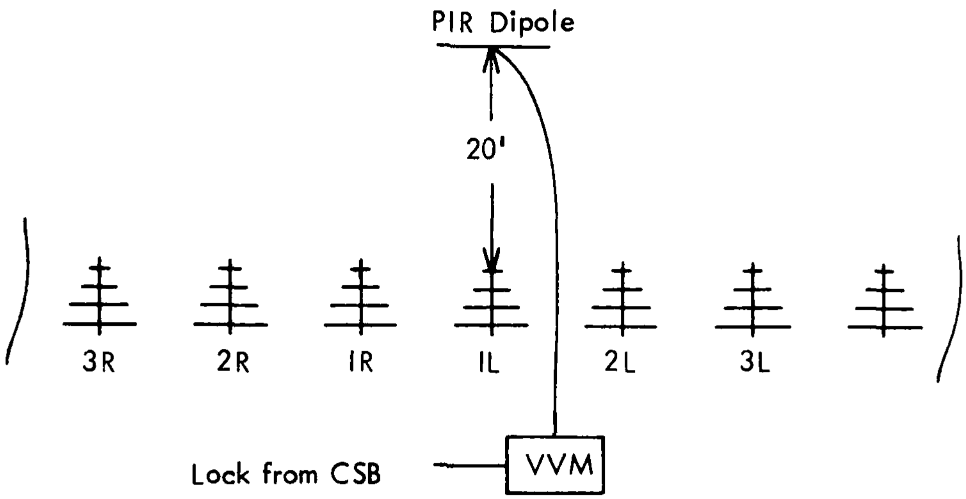


Figure 37. Mutual Coupling Test Set-Up.

Condition	Antenna 1L	Antenna 2L
Normal	1.00 0° Reference	.190 −114°
Load 1L & 1R	————	.100 +97°
Load 1L, 1R, 3L	————	.036 2° Design value = .036 0°

Table 5. Mutual Coupling Tests on Redlich Array.

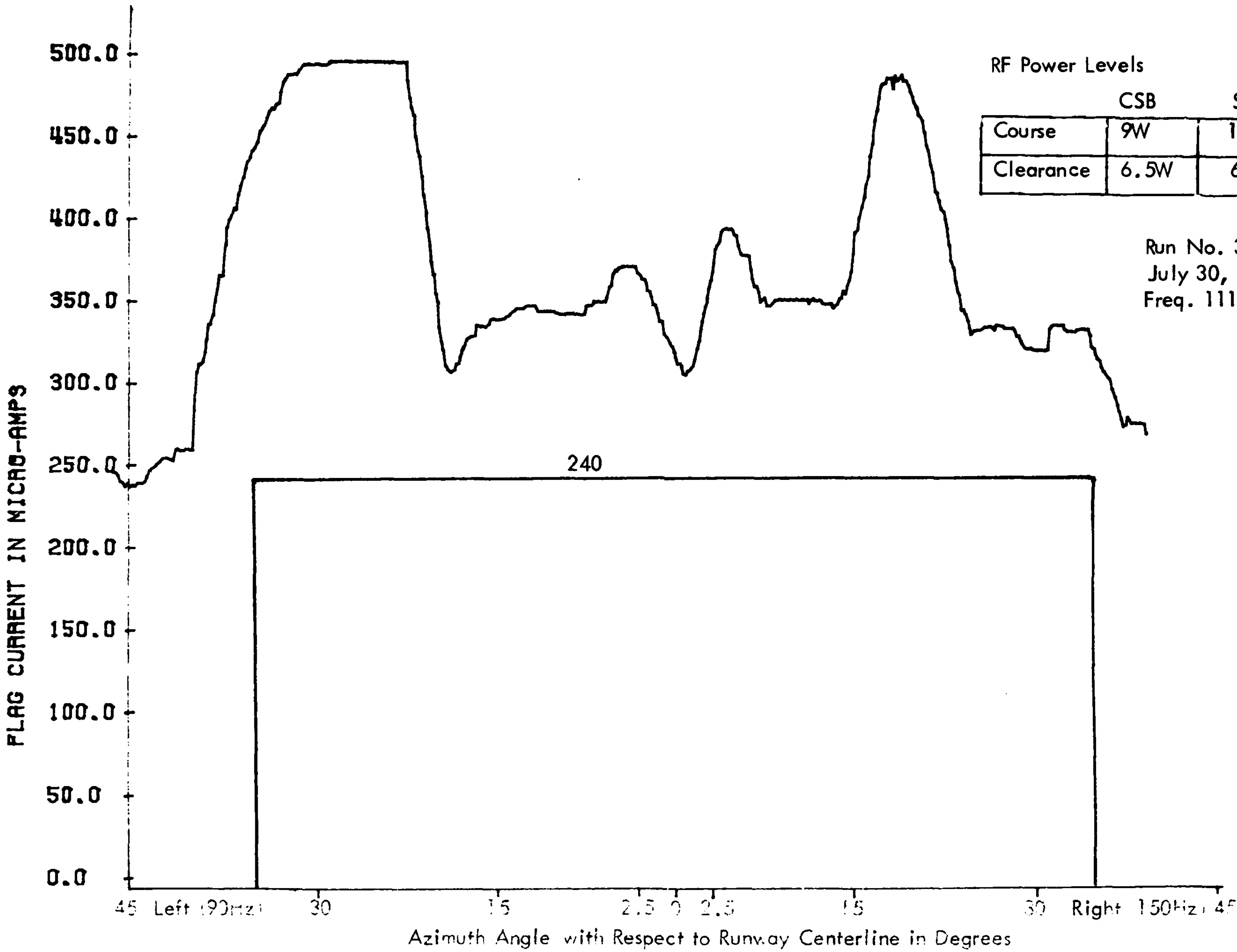


Figure 38. Measured Flag Current of Redlich Localizer With Clearance CSB Signal Removed from Antennas 2L and 2R.

RF Power Levels

	CSB	SBO
Course	9W	110mW
Clearance	6.5W	600mW

July 30, 1981
Freq. 111.9 MHz

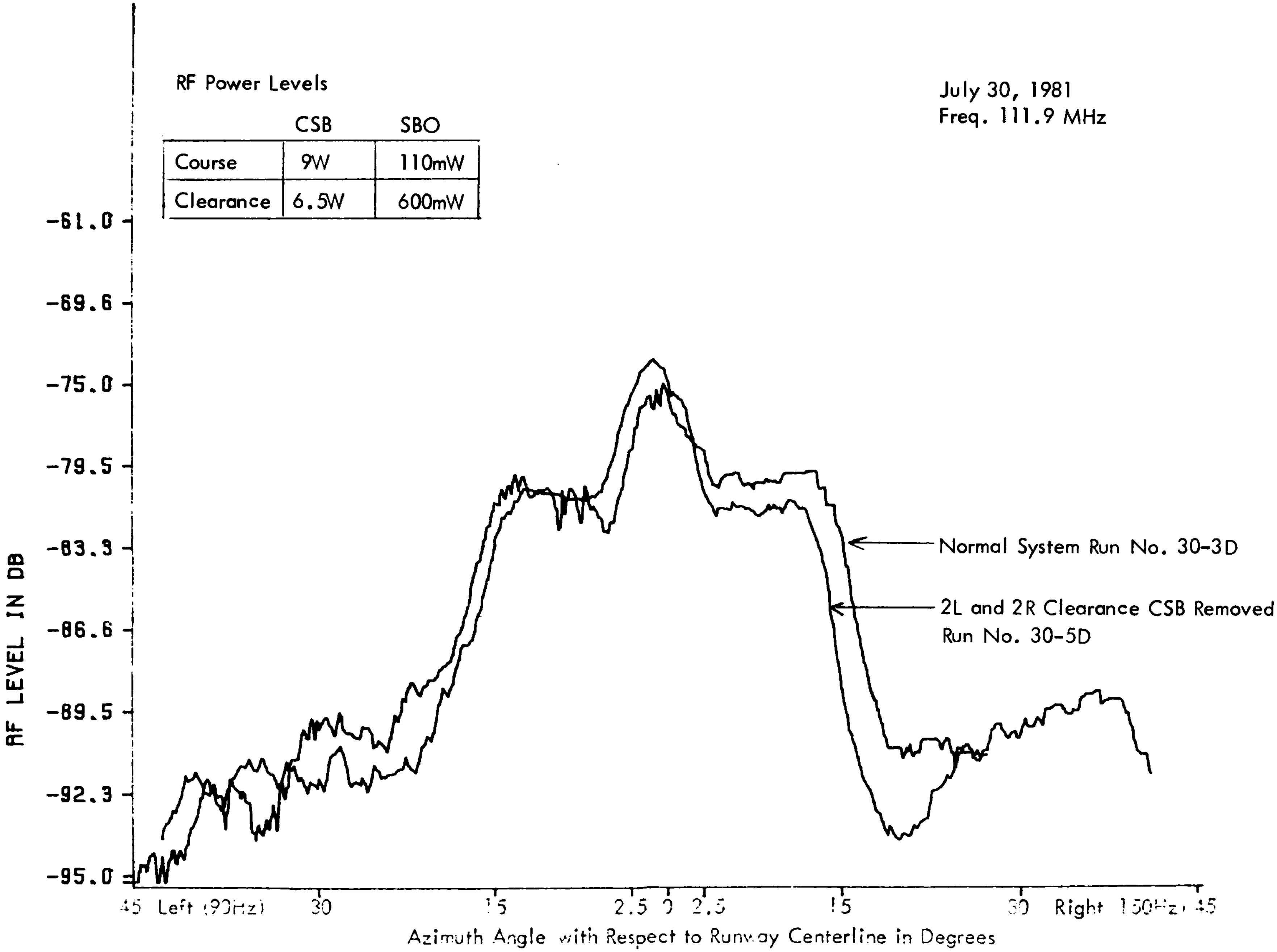


Figure 39. Comparison of Normal System and Antenna 2L and 2R Clearance Signal Removed.

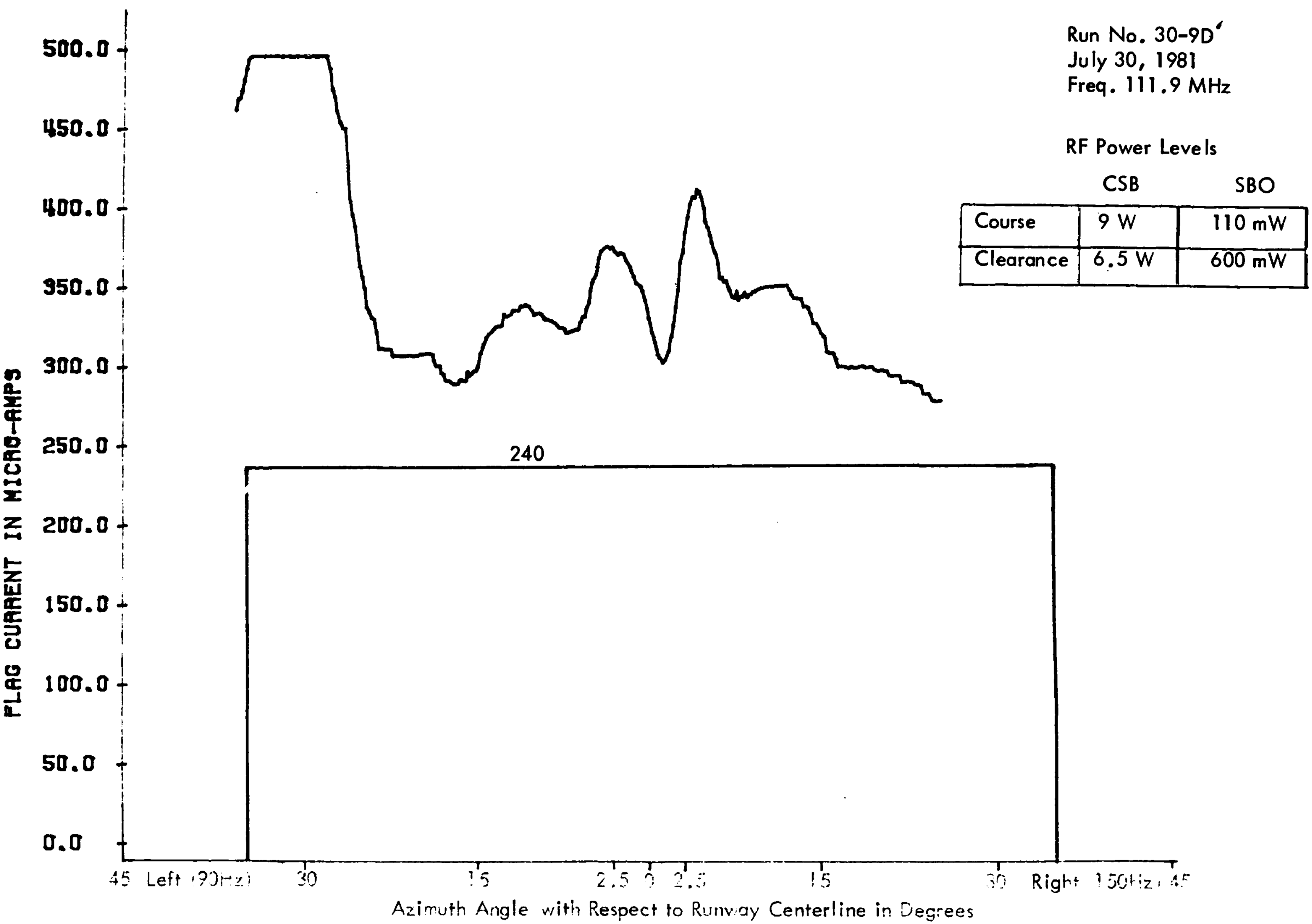
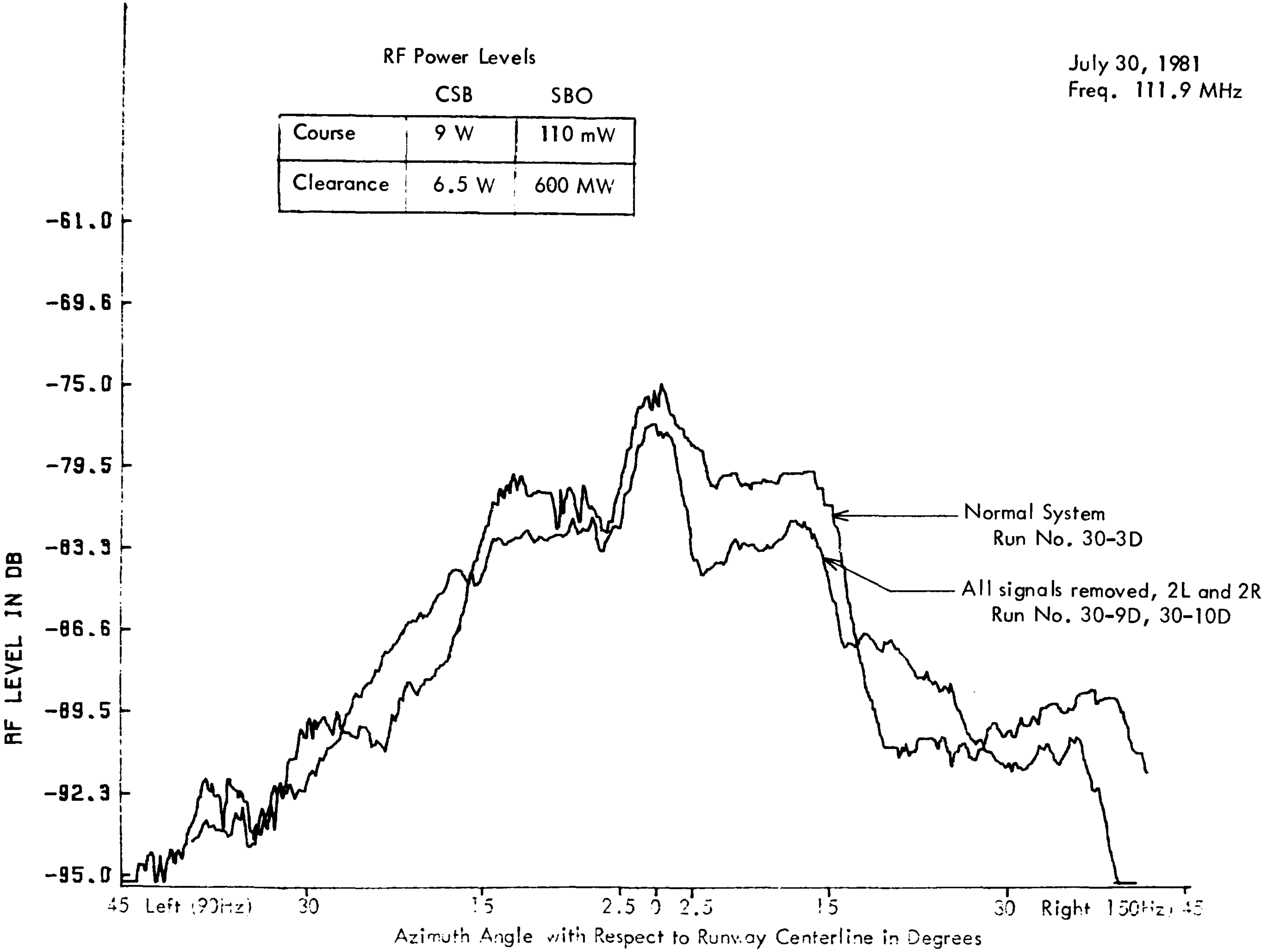


Figure 40. Measured Flag Current of Redlich Localizer with all Signals Removed from Antennas 2L and 2R.



RF Power Levels

	CSB	SBO
Course	9 W	110 mW
Clearance	6.5 W	600 MW

Figure 41. Comparison of AGC Normal System and Antennas 2L and 2R All Signals Removed.

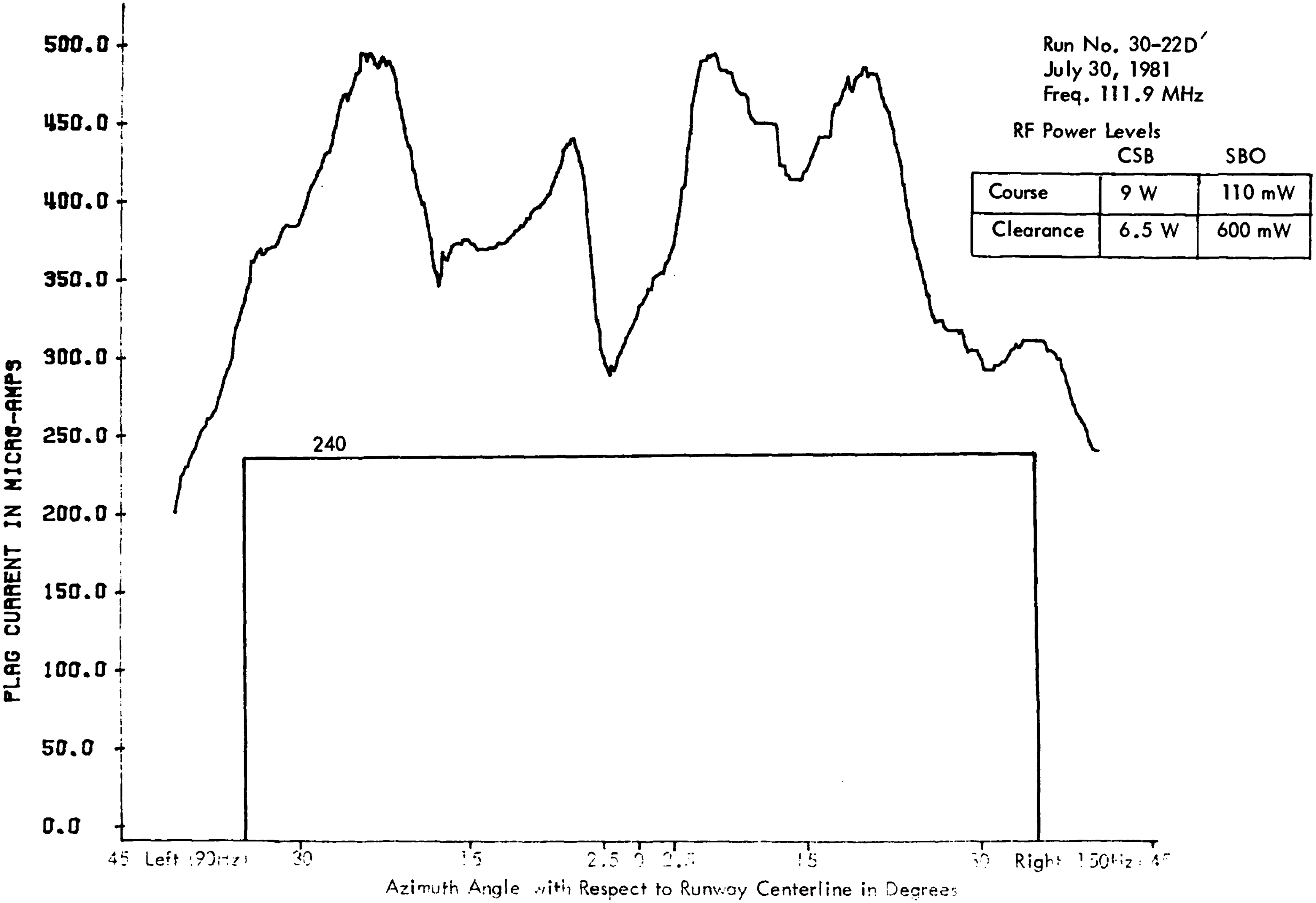


Figure 42. Measured Flag Current for the Redlich Localizer. Antennas Reversed.

radiated signal. In other words, the clearance CSB and SBO are the dominant factors in the flag and CDI values since the aircraft receiver is captured by the clearance at these points. Recognizing this fact, the anomaly probably exists within the clearance portion of the array. The CSB portion has been eliminated as a likely cause since the combined AGC patterns are symmetrical. This leaves the SBO pattern.

Figure 43 shows the measured clearance SBO pattern. Note the lack of symmetry between the north and south portions of the pattern. This asymmetrical condition in the SBO pattern could be contributing to the asymmetrical flag measurements. As stated earlier, it appears that the anomaly is environmentally induced.

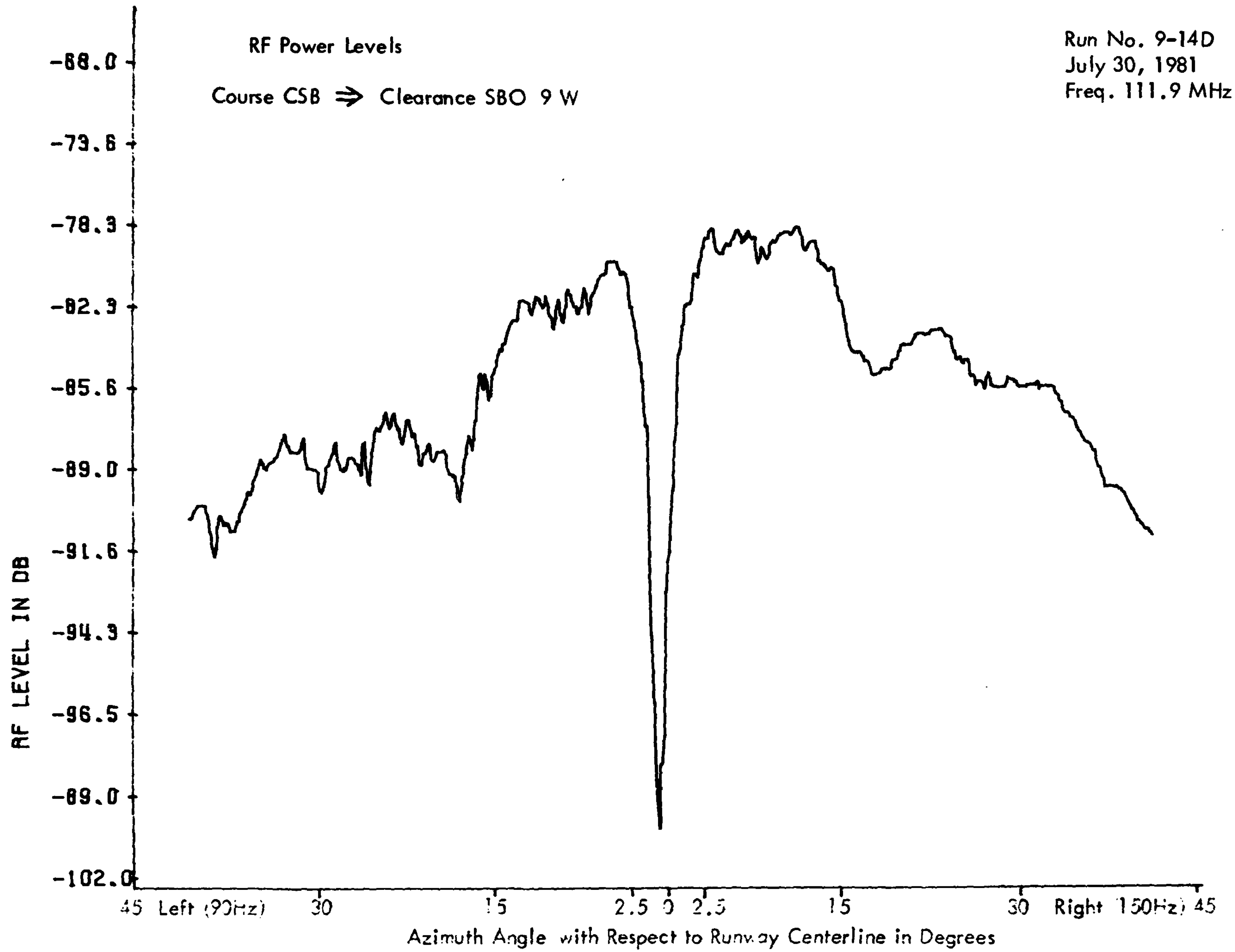


Figure 43. Measured Clearance SBO Pattern for the Redlich Localizer.

CONCLUSIONS.

Flight measurements conducted on the Redlich 14-element localizer have led to the following conclusions.

1. Clearance and signal strength levels are adequate for both the normal system (course width 3.0°) and the broad alarm case (course width 7.2°) at a frequency of 111.9 MHz.

2. Based on the measurements at the Tamiami test site, usable distance and coverage exceed the 22-8 values except between 16° and 19° on the left side of the array.

3. The measured half-power beamwidth of the Redlich localizer compares favorably with that of the 22-8. (5.1° for the Redlich localizer and 5.0° for the 22-8, both measured at 111.9 MHz.)

4. Course alignment and structure meet flight inspection tolerances based on CDI measurements using visual references only.

5. The course sideband only (SBO) pattern as measured at 111.9 MHz with the log periodic dipole antennas has a sidelobe at approximately 60 degrees - 16 dB from the main lobes. This is a result of a substitution of the LPD for the "O" ring-type antenna. The "O" ring was used in the original design and provided at least -22 dB at the 60-degree point.

RECOMMENDATIONS.

A probing technique could be developed for the Wilcox LPD antennas. The high side lobe levels encountered in the course SBO patterns at approximately 60° either side of the array center should be lowered in order for the array to more closely resemble the characteristics of the 22-8 localizer. One suggested method for reducing these levels is to use the O-ring or TWA type of traveling wave antenna. This could have the effect of reducing the side-lobe levels by as much as 6 dB through the lower relative level of the single antenna radiation pattern at the 60-degree point.

INVESTIGATION OF THE WILCOX 16-ELEMENT, TWO-FREQUENCY, WIDE APERTURE LOCALIZER

The experimental evaluation of Category III quality localizer systems designed for installation at potential problem sites is continued in this section. Earlier sections presented calculated and measured results for the 22-8 combined array and for the Redlich 14-element localizer. The system documented here is the Wilcox 16-element array.

The Wilcox 16-element, two-frequency localizer was installed at the Ohio University Tamiami test site using distribution unit hardware provided by the Wilcox Electric Company. An initial investigation of the system was conducted late in July 1981 but interrupted by the air traffic controllers strike. The tests were subsequently completed early in September. The measurements of the Wilcox system performance are intended input to provide the data to allow comparison of the Wilcox, 16-element localizer and the Alford 22-8 system.

DATA COLLECTION.

Airborne data collection was accomplished using the Ohio University Mark III mini-lab installed in a Beechcraft model 36 aircraft. All flight data were recorded on analog strip chart recordings. These recordings have been digitized for computer storage and for analysis purposes. All recordings presented in this paper are reproduced from this digital data.

Table 6 lists the flight measurement data deemed necessary for an evaluation of the localizer system. In addition to the data presented in the table, the required measurements for a two-frequency localizer system as stated in the United States Standard Flight Inspection Manual were checked.

Condition	A/C Track	Variable Recorded	Parameters	Crucial/ Items
Normal 2-freq. operation	35° arc	AGC CDI Flag	111.9 MHz 108.5 MHz Course width 3.0° and broad	Clearance level Signal level
Course only	90° arc	AGC	111.9 MHz	SBO sidelobe
CSB into SBO			108.5 MHz	level
Course only	10° arc	AGC	111.9 MHz	1/2 power
CSB only			108.5 MHz	beamwidth
Normal 2-freq. operation	10° 10.35°	AGC	111.9 MHz 108.5 MHz	Usable distance (relative based on TMB power in)
Normal 2-freq. operation	Approach	CDI Diff. Amp Theodolite Flag	111.9 MHz 108.5 MHz	Structure Roughness

Table 6. Required Data for Evaluation of the Wilcox 16-element Localizer.

MEASURED DATA.

Following the installation of the Wilcox localizer, flight measurements of the system were conducted for an initial evaluation. These initial measurements indicated that an anomaly existed in some portion of the system. A hole in the clearance at approximately 5° south put the system out of tolerance according to the U. S. Flight Inspection Manual. Measurements were made of the clearance radiation patterns to try and locate the difficulty. These measurements were inconclusive in determining the anomaly and it was decided to conduct phase and magnitude measurements on the distribution unit.

The measurements of the distribution unit resulted in the discovery of a faulty connector. The connector was replaced and flight measurements were continued in early September after air traffic control returned to more nearly normal operational status.

As stated earlier the measurements of interest for use in the comparison of the 22-8 and eventually to the Redlich array are listed in table 6. This set of measurements is the same as those used in the comparison of the Redlich array to the 22-8 system. Using this table as a guide, the tests were begun.

The parameters of the system were measured at a frequency of 111.9 MHz +4 KHz for the course transmitter and -4 KHz for the clearance transmitter and at 108.5 MHz with the same offsets for the course and clearance transmitters.

Initially the course widths were set to 2.9 degrees at 111.9 MHz and to 3.3° at 108.5 MHz. These measured widths resulted in symmetry of 45%-55% for the 2.9° width and 48%-52% for the 3.3° width. The specified tolerances for the symmetry are 45-55% with facility in normal condition.

Clearance measurements were then conducted for each of the frequencies with their respective width settings. Figures 44 and 45 show the measured CDI for the 111.9 MHz frequency and for the 108.5 MHz frequency respectively.

The levels remain well above the required 150 microampere level in localizer Sector 2. In addition, the required linear increase to 175 microamperes and the maintenance of this level to 10° in Sector 1 is also achieved.

Broad course widths of the ssytem were then established at 5.4° for the 111.9 MHz frequency and at 5.6° for the 108.5 MHz frequency. These widths were the maximum achievable settings adjusting only the course SBO power levels. Symmetry for these widths was 50-50% for the 5.4 degrees width and 50-50% for the 5. Clearance measurements for the two broad width settings are shown in figures 46 and 47. The tolerances for ILS Localizer Sector 2 are again met. In Sector 1 the tolerances are also met, but there is a small amount of non-linearity in the cross over. This is due to the narrow beamwidth of the course carrier signal of this particular design.

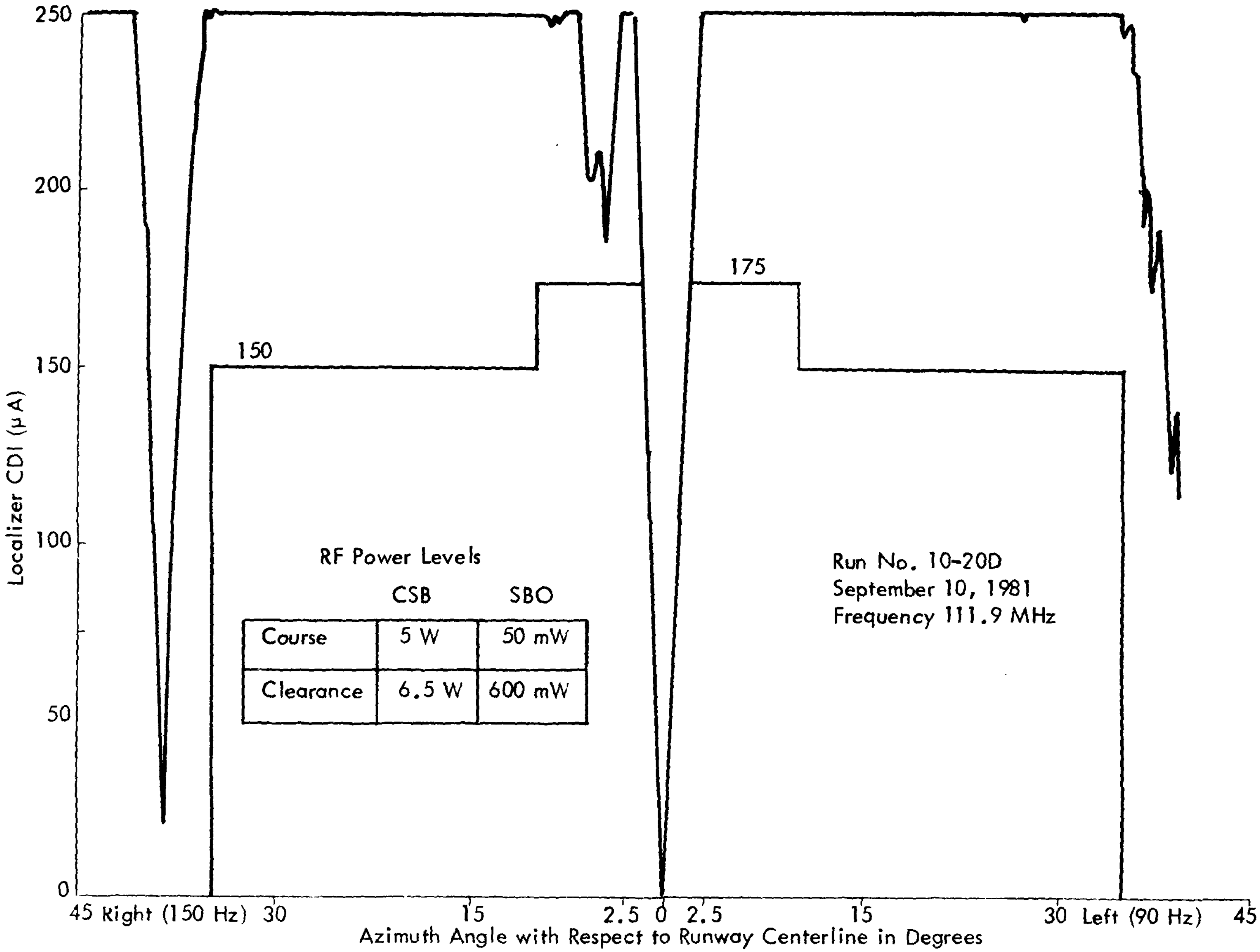


Figure 44. Measured CDI Current for the Wilcox 16-Element Localizer with Path Width of 2.9°.

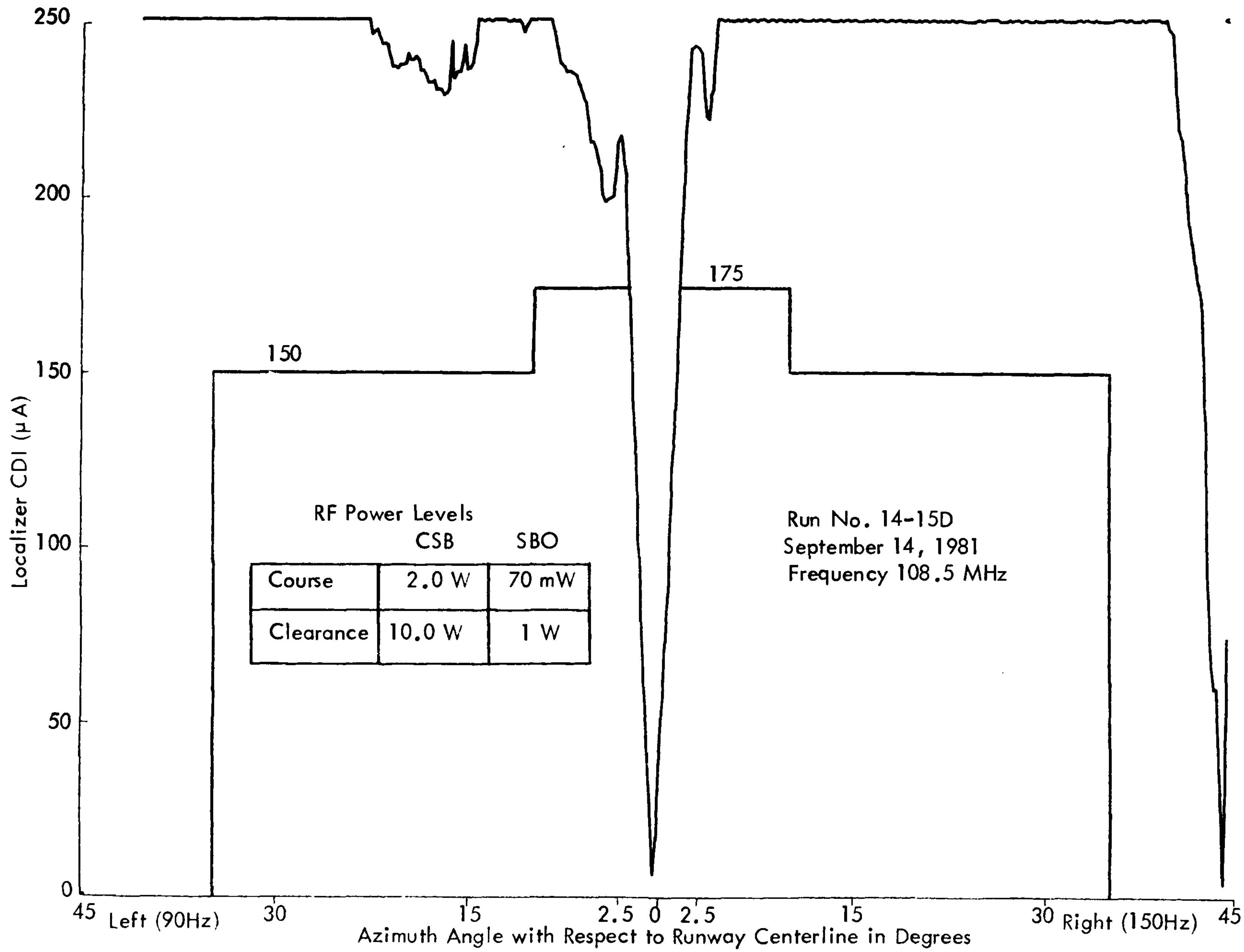


Figure 45. Measured CDI Current for the Wilcox 16-Element Localizer with a Path Width of 3.3°.

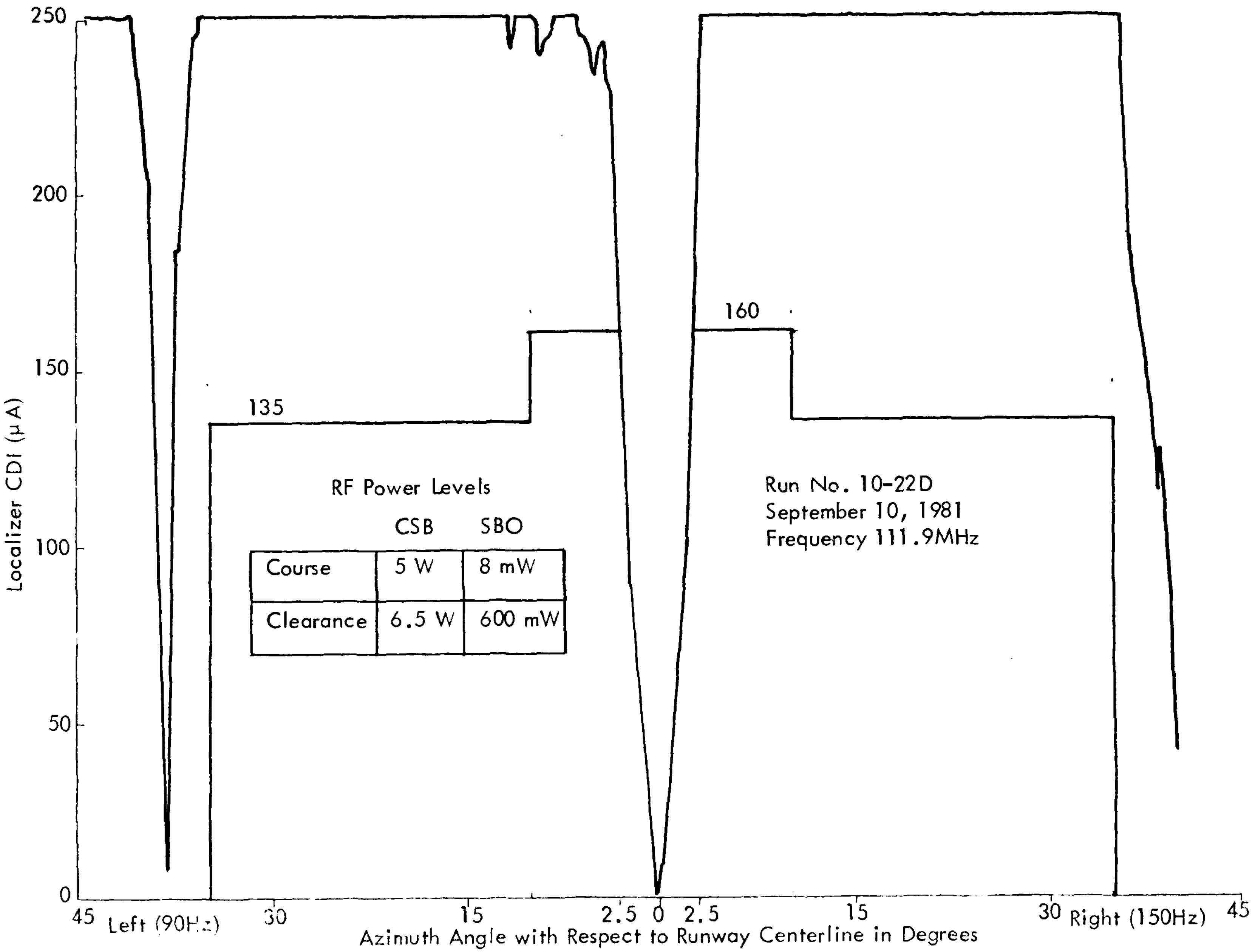


Figure 46. Measured CDI Current for the Wilcox 16-Element Localizer with a Path Width of 5.4°.

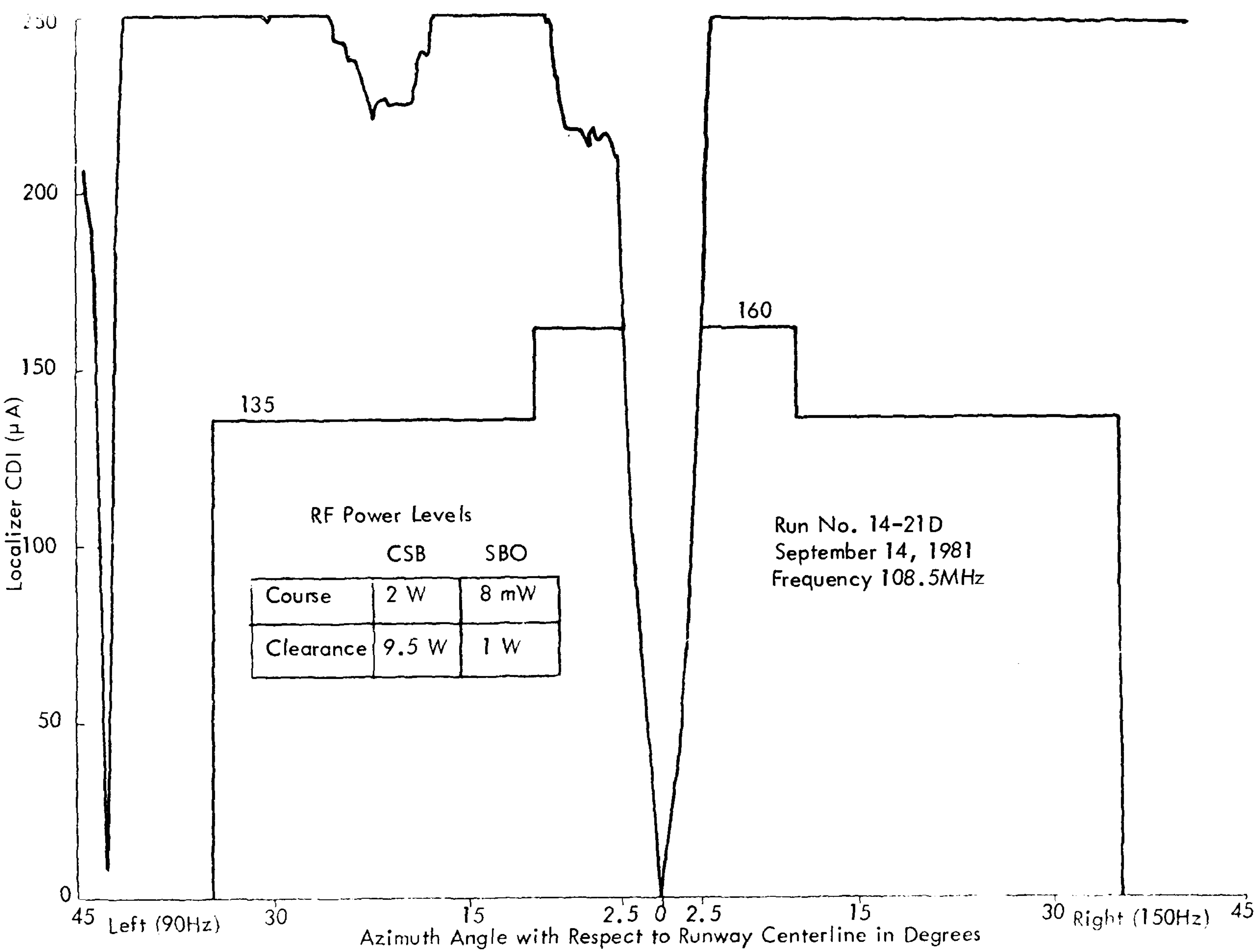


Figure 47. Measured CDI Current for the Wilcox 16-Element Localizer with a Path Width of 5.6°.

This non-linearity conceivably could be reduced by simultaneously adjusting the clearance SBO level while adjusting that of the course transmitter.

An important parameter in a Category III quality system is the course structure. The most influential portion of the localizer system on this parameter is the course sideband radiation pattern. A high sidelobe level present in this pattern could cause severe course bends if a reflecting structure were to be located near the azmuthal angle of the sidelobe. Therefore, a ±90° sideband-only radiation pattern measurement was made.

Figures 48 and 49 show the SBO radiation pattern measurements for frequencies of 111.9 MHz and 108.5 MHz respectively. The highest sidelobe level measured at 111.9 MHz is -14 dB from the main lobes and is at approximately 10°. With the system tuned to 108.5 MHz, the sidelobe at 10° is now -17 dB with all other lobes below this level.

Course carrier beamwidth checks were also performed. The plot of figure 50 shows the measured half-power beamwidth to be 3.8° at 111.9 MHz. A similar plot is provided for 108.5 MHz in figure 51 showing a 3.2° beamwidth. These are substantially more narrow than that measured for the 22-8 (5.0°).

Usable distance measurements and the coverage area checks were completed for both 111.9 MHz and 108.5 MHz. The results of these tests are compared against the published specifications of OAP 8200.1 217.5 and the measured data of the 22-8 localizer in table 7 and figure 52. The usable distance was checked on centerline at a distance of 18 NM at an altitude of 1500 feet for the 111.9 MHz frequency with a course input power of 5 watts as measured in the transmitter hut. From the table it is noted that the level is 11.2 μv. This is 7 dB above the required 5 μv level for the localizer coverage area.

The coverage at 111.9 MHz, shown in figure 52 indicates that the 5 μv requirement in Sector 2 is met with a normalized power of 7 watts.

The usable distance and coverage measurements at a frequency of 108.5 MHz were made with a course input power of 2 watts and a clearance input power of 10 watts. This resulted in an on-centerline course to clearance power ratio of 12.5 dB, which is greater than the 10 dB minimum specified in 8200.1. A 10 μv level was recorded at 18 NM on centerline and the coverage area and levels are as shown in figure 53.

The polarization of the course was checked and found to be within the ±5 microampere tolerance limit of 8200.1.

Flag current measurements were made at 111.9 MHz and 108.5 MHz. The plots of these measurements for course width settings of 5.4° at 111.9 MHz and 5.6° at 108.5 MHz are shown in figures 54 and 55. The flag currents shown are for the combined two-frequency system and as noted in the figures the levels are above the 240 microampere minimum throughout the ±35° coverage area.

The alignment and structure measurements at each frequency are considered inconclusive due to a failure in the differential amplifier section of the airborne equipment.

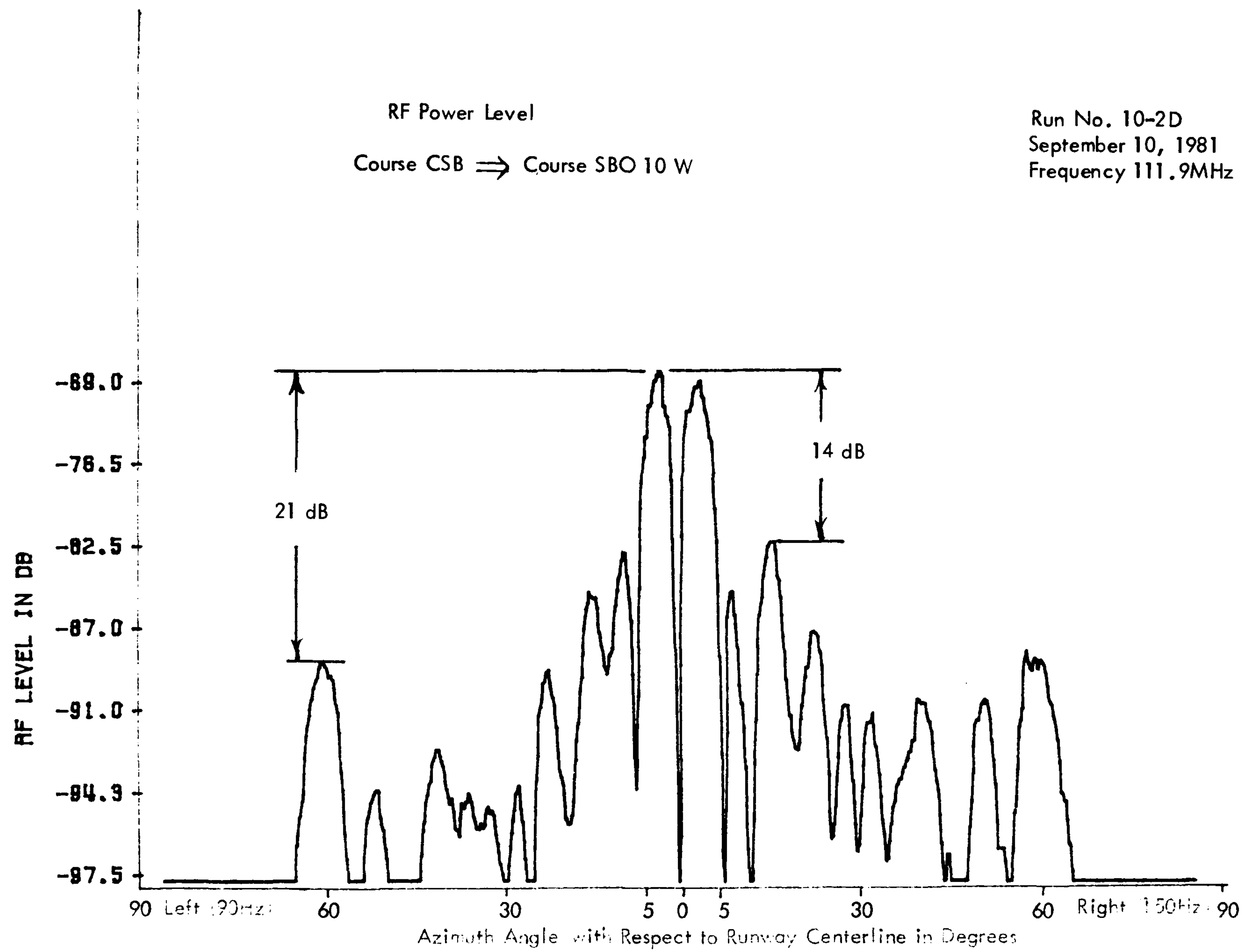


Figure 48. Measured Course Sidebands-Only Radiation Pattern for the Wilcox 16-Element Localizer.

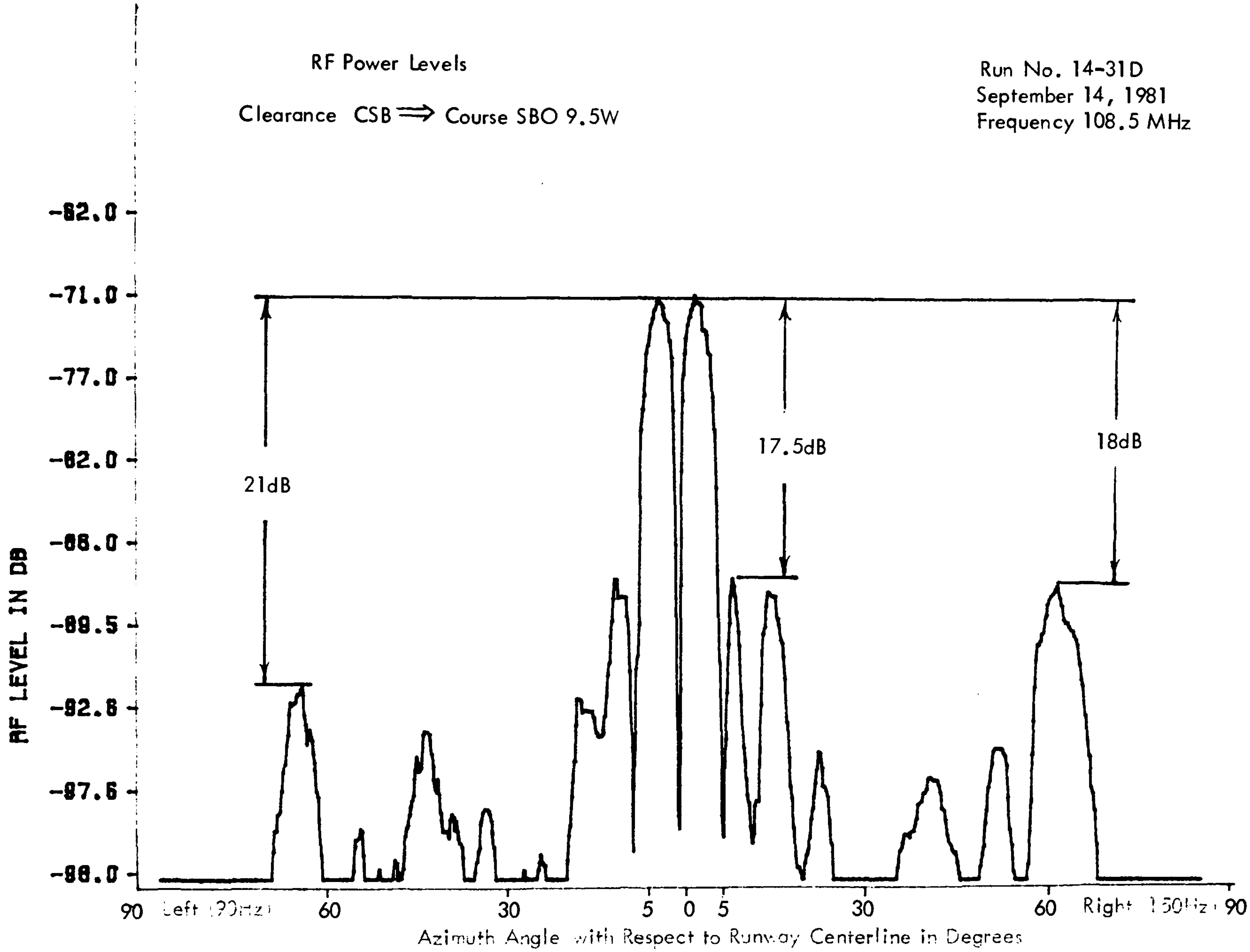
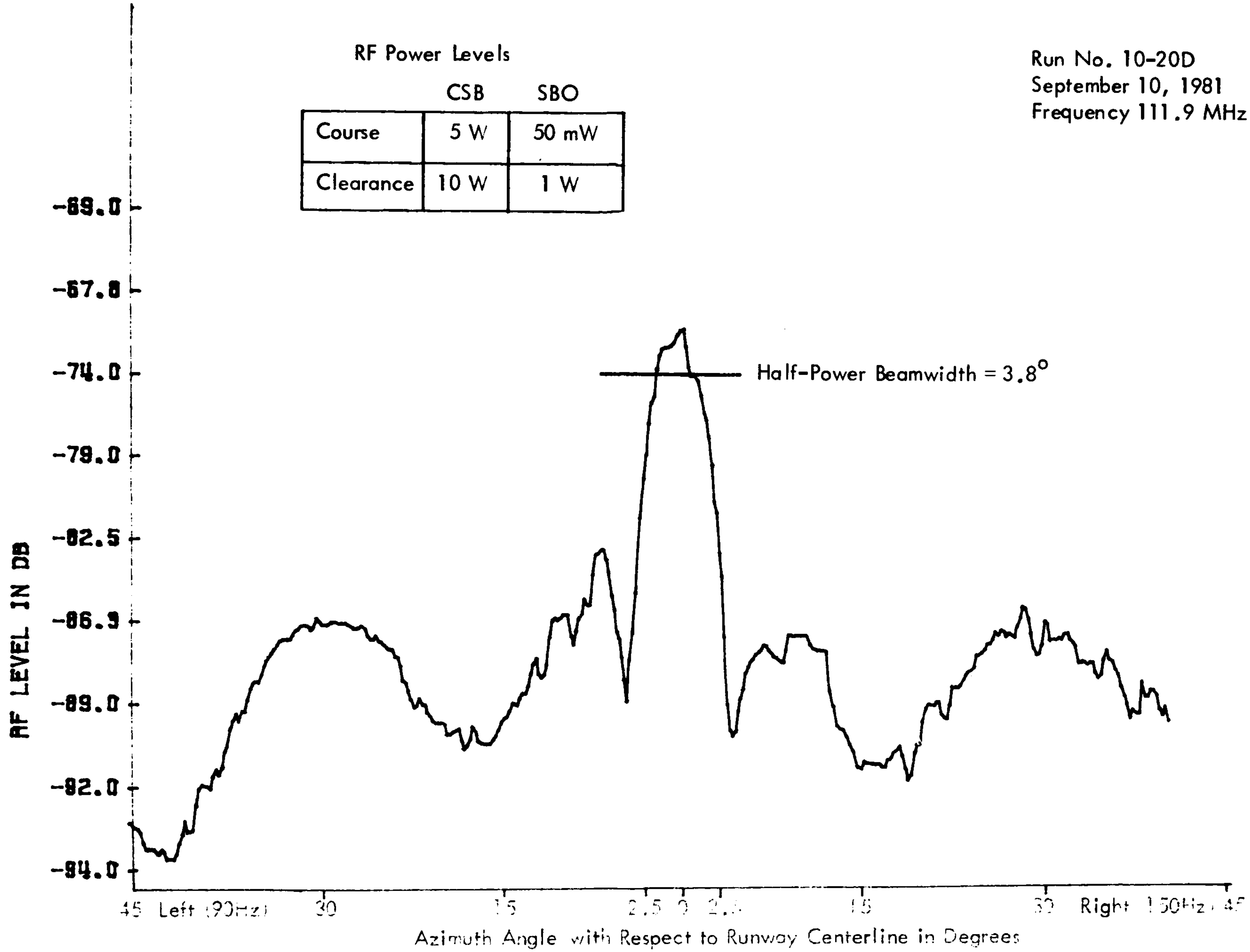


Figure 49. Course Sidebands-Only Radiation Pattern Measurement for the Wilcox 16-Element Localizer.



	CSB	SBO
Course	5 W	50 mW
Clearance	10 W	1 W

Figure 50. AGC Plot of the Wilcox 16-Element Localizer Showing Half-Power Beamwidth of 3.8°.

RF Power Levels

	CSB	SBO
Course	2 W	70 mW
Clearance	10 W	1 W

Run No. 14-15D
September 14, 1981
Frequency 108.5 MHz

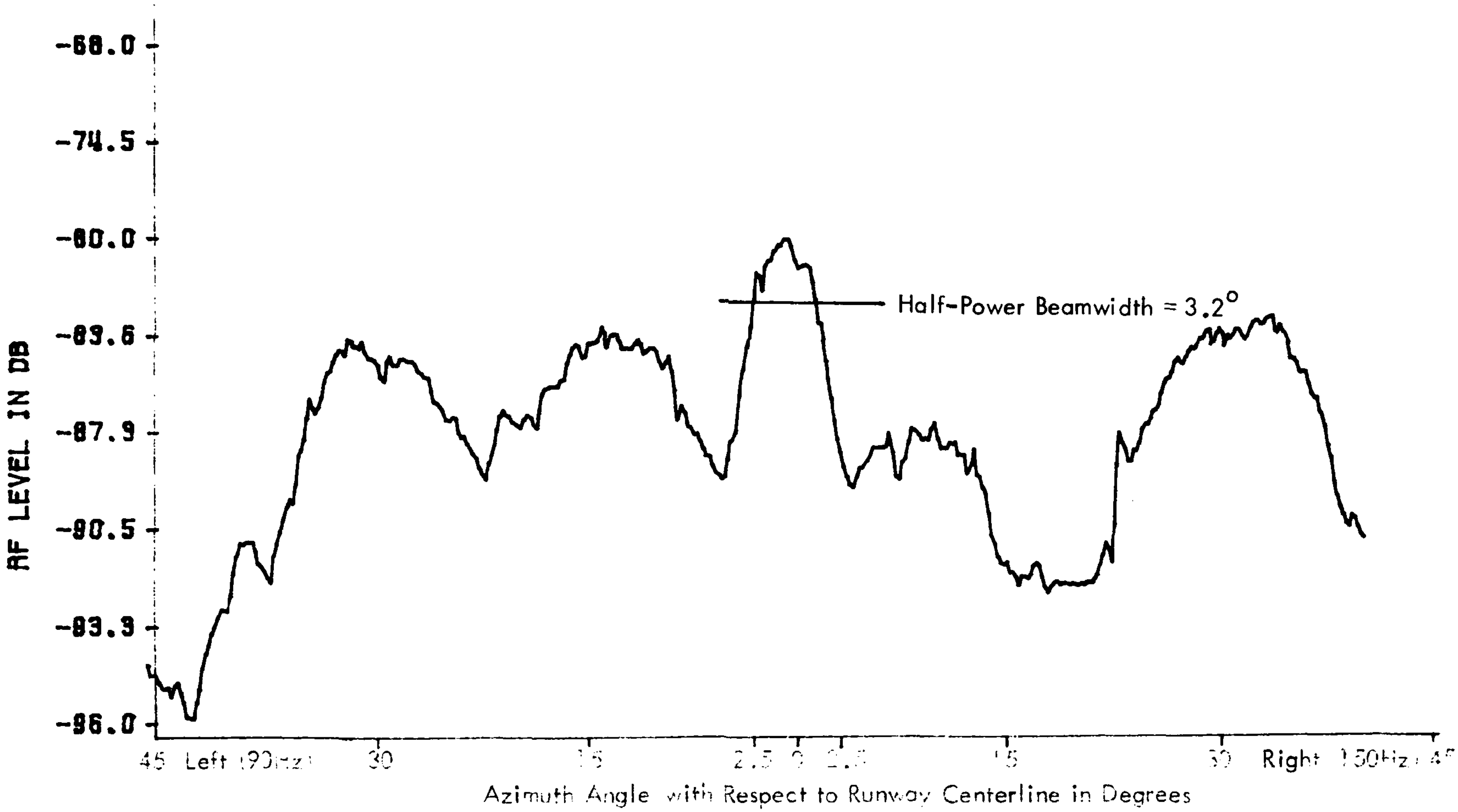


Figure 51. AGC Plot of the Wilcox 16-Element Localizer Showing Half-Power Beamwidth of 3.2° at a nominal Frequency of 108.5 MHz.

Parameter	8200.1 217.5 (CHG 32)	Wilcox Measured Value	22-8 Measured Value
Usable Distance 111.9 MHz	5 µv @ 18 NM	11.2 µv @ 18 NM 1500' AGL	9 µv
Coverage 111.9 MHz	5 µv @ 10 NM Sectors 1 & 2	See figure 52	See figure 52
Usable Distance 108.5 MHz	5 µv @ 18 NM	10 µv @ 18 NM 1500' AGL	————
Coverage 108.5 MHz	5 µv @ 10 NM Sectors 1 & 2	See figure 53	————

Table 7. Usable Distance and Coverage Measurements of the Wilcox 16-Element Localizer Compared to the 22-8 Localizer and the U.S. Standard Flight Inspection Manual.

Input Powers Course 2W @ 108.5 MHz Course 5W @ 111.9 MHz
Clearance 9W @ 108.5 MHz Clearance 10W @ 111.9 MHz

RF Power Levels

	CSB	SBO
Course	5 W	50 mW
Clearance	6.5 W	600 mW

Run No. 10-20D
September 10, 1981
Frequency 111.9 MHz

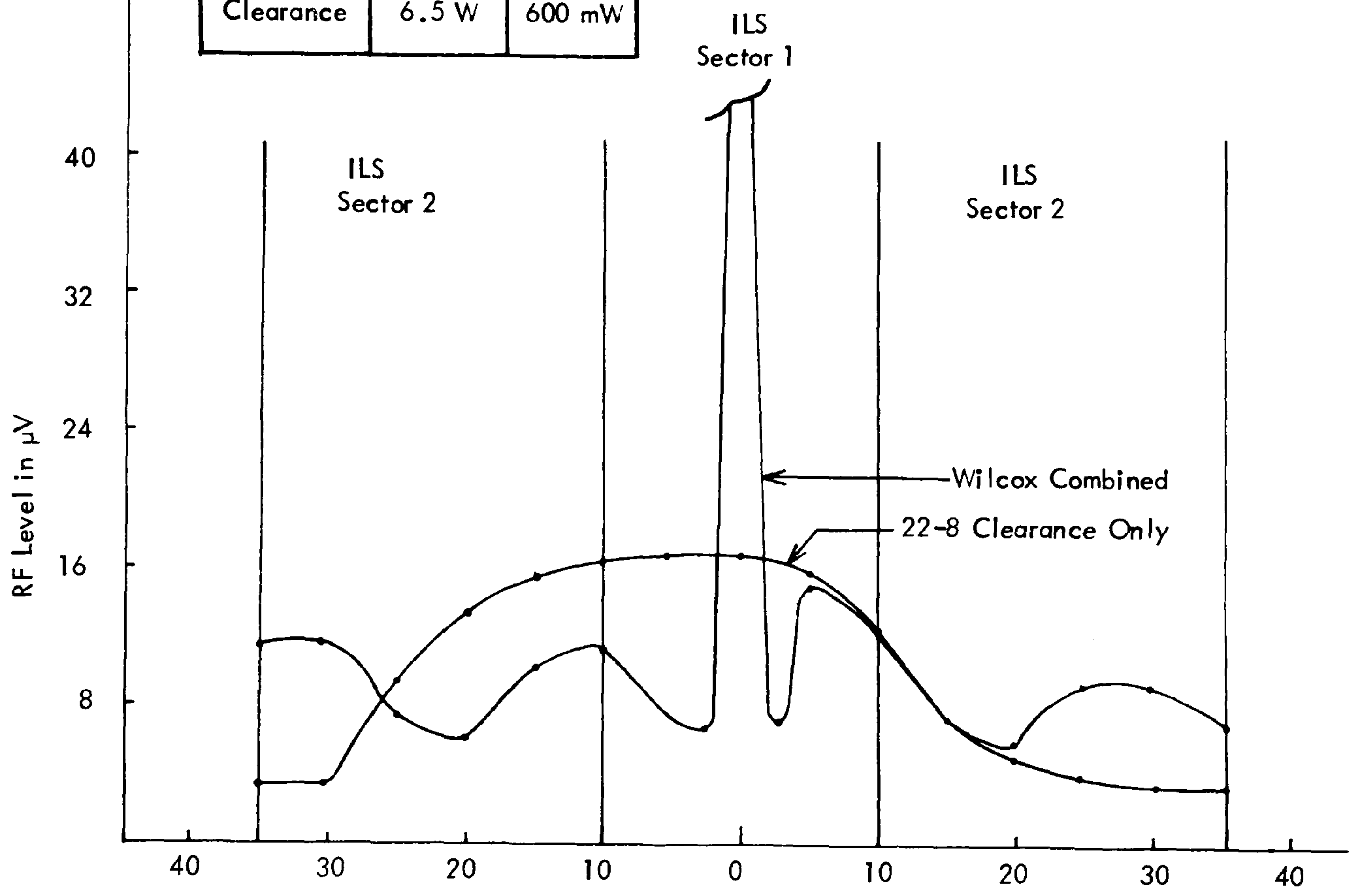


Figure 52. Measured RF Level for the Wilcox Localizer.

Run No. 14-140
September 14, 1981
Frequency 108.5 MHz

RF Power Levels

	CSB	SBO
Course	2 W	70 mW
Clearance	10 W	1 W

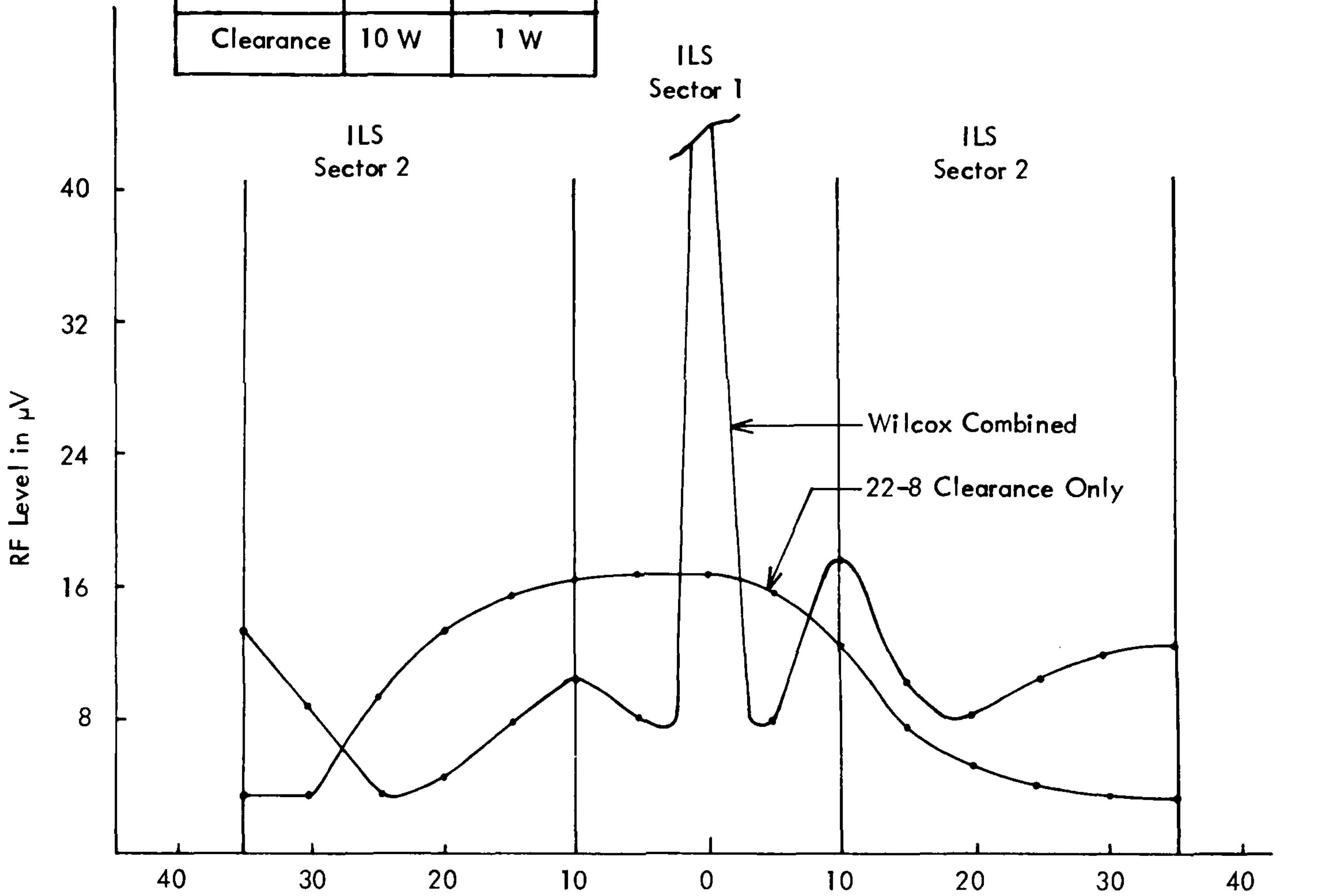


Figure 53. Measured RF Level for the Wilcox Localizer.

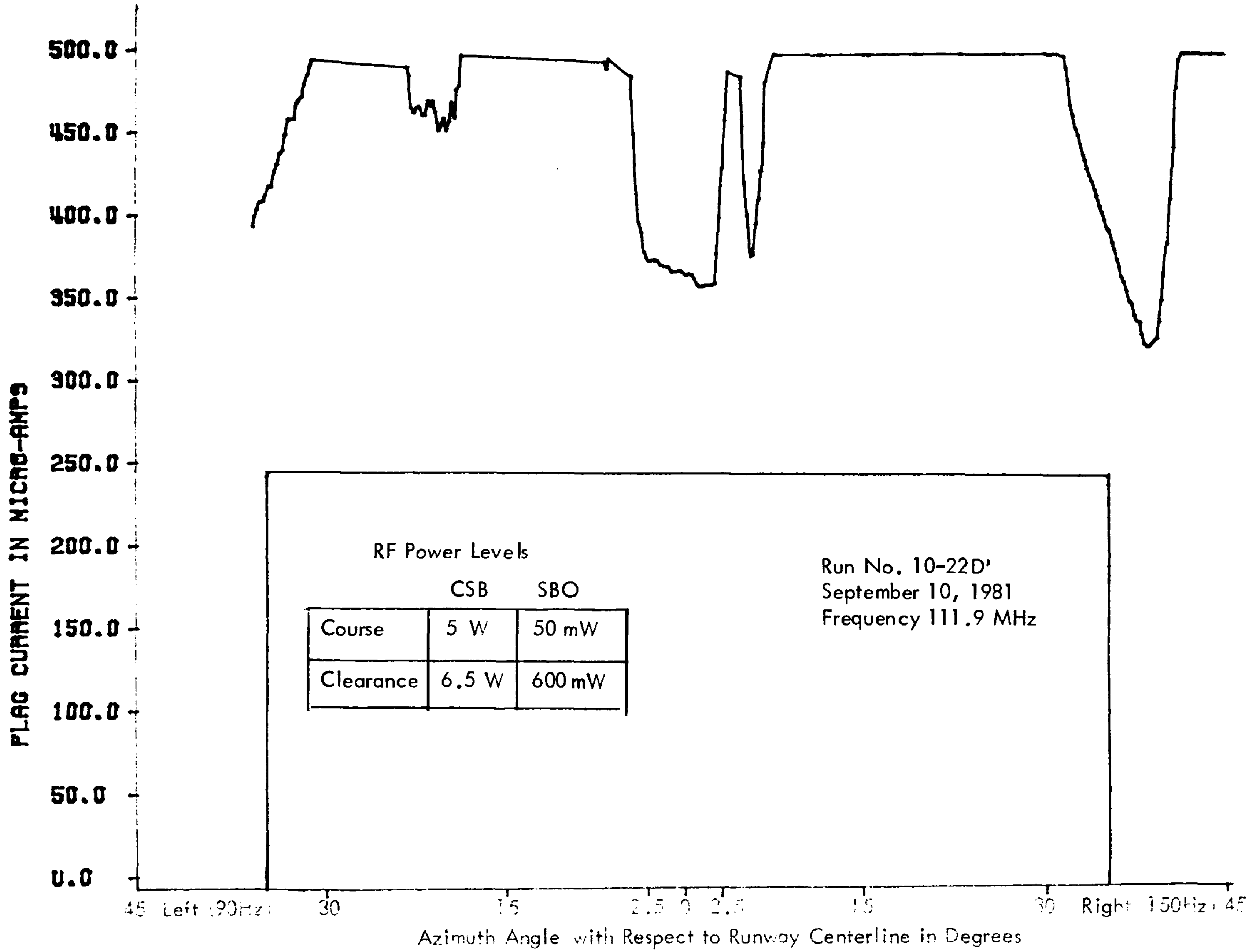


Figure 54. Measured Flag Current for the Wilcox Localizer. Minimum flag current levels are indicated by the box.

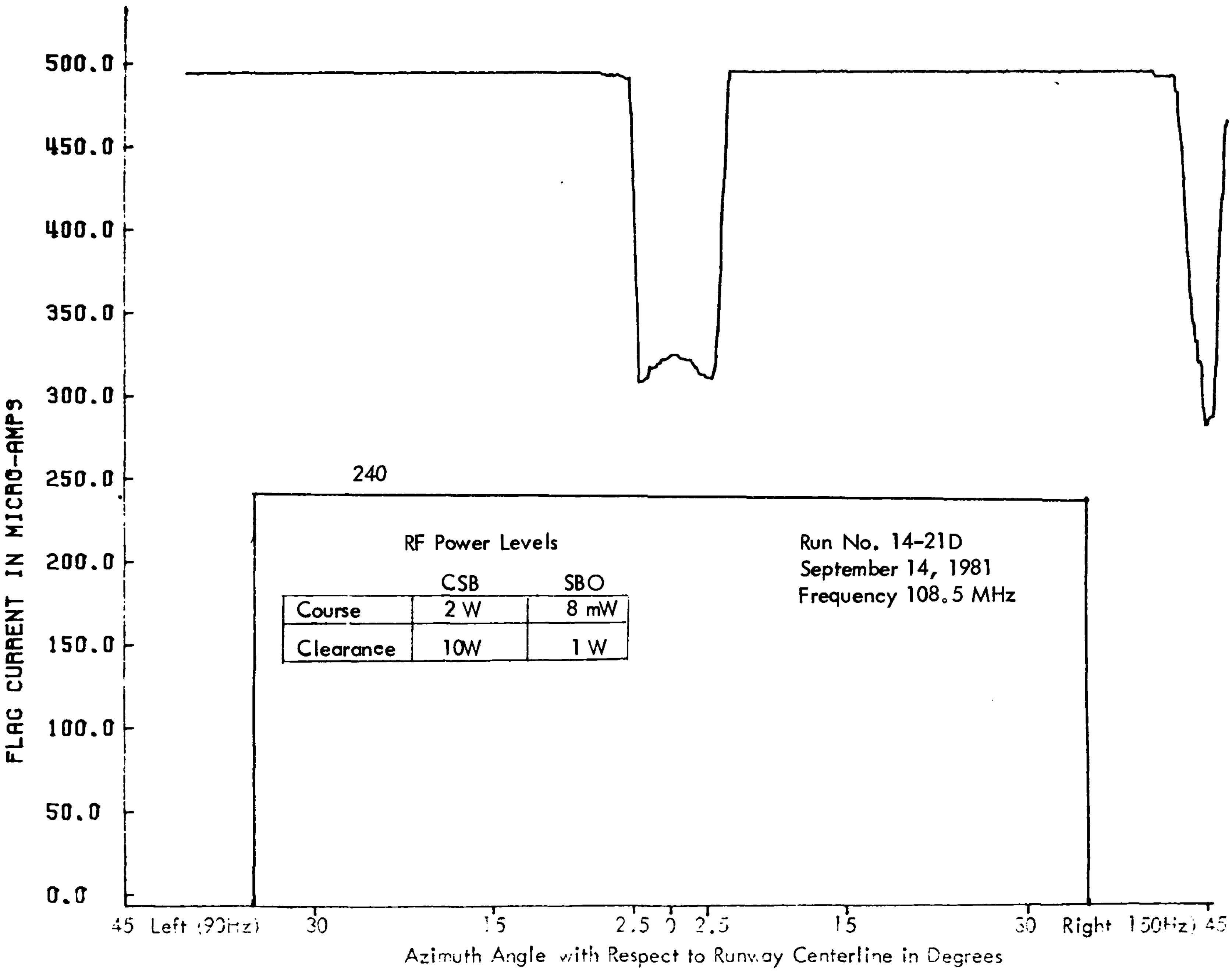


Figure 55. Measured Flag Current for the Wilcox Localizer. Minimum flag current levels are indicated by the box.

SUMMARY AND CONCLUSIONS.

The measured data of the Wilcox 16-element localizer is summarized and compared against flight inspection tolerances in table 8. From the table the following conclusions are drawn.

1. Adequate clearance is present in the required ±35° area for both the normal and broad course widths at 111.9 MHz and 108.5 MHz.

2. Usable distance and coverage tolerances can be met based on the available power at Tamiami.

3. The half-power beamwidth of the Wilcox localizer is measured to be 3.8° at 111.9 MHz and 3.2° at 108.5 MHz.

4. The course sidebands only (SBO) radiation pattern shows sidelobes at approximately 10° which are -14 dB and -17 dB for 111.9 MHz and 108.5 MHz respectively from the main lobes. The sidelobes at the 60° point are -18 dB from the main lobes.

Symmetry, flag, and polarization requirements for the system are all met.

Parameter	Frequency MHz	Course Width Degrees	Measured Value	Tolerance per 8200.1
Course/ Clearance	111.9	-----	-----	10 dB
Power Ratio	108.5	-----	12.5 dB	10 dB
Symmetry	111.9	2.9	48-52%	45-55%
	111.9	5.4	50-50%	45-55%
	108.5	3.3	45-55%	45-55%
	108.5	5.6	50-50%	45-55%
Coverage	111.9	2.9	See table 7 fig 52	5 μv
	108.5	3.3	See table 7 fig 53	5 μv
Flag	111.9	2.9	>300 μA	>240 μA
	108.5	3.3	>250 μA	>240 μA
Polarization	111.9	2.9	-----	± 5 μA
	108.5	3.3	None	± 5 μA
Clearance	111.9	2.9	See fig 44	Sector 1
	111.9	5.4	See fig 46	Linear incrase to
	108.5	3.3	See fig 45	175 μA. Maintain to
	108.5	5.6	See fig 47	10°. >150μA 10-35°.

Table 8. Summary of Wilcox Localizer Measurements Compared to the Tolerances of the U.S. Flight Inspection Manual. All measurements noted are within the specified tolerances.

FAULT CORRELATION TESTING OF THE REDLICH

14-ELEMENT ARRAY MONITOR SYSTEM

In October of 1981 an analog localizer monitoring system was chosen for implementation and testing with the Redlich wide-aperture localizer system. This system designed by Dr. R. Redlich was chosen to overcome difficulties in combining of the course and clearance signals which would arise if a more traditional system (e.g. FA-9759/15) were used with the Redlich array.

DESCRIPTION OF ANALOG MONITOR.

The system uses a phased-line technique to sample the analog of three positions on the localizer DDM pattern. The three monitored positions are 0° (centerline), 2° right (150 Hz, width measurement), and 27.5° right (150 Hz, clearance). The 0° and 2° points are chosen for the on-course and off-course monitor points of current monitors. The 27.5° position is chosen to provide monitoring of the clearance portion of the two-frequency system in an analog fashion. This eliminates the requirement for monitoring both an on-course and off-course position for the separate clearance frequency and gives a better indication of the actual levels in the clearance area.

Signals from the monitor ports of each element in the array are combined by an addition of the signals after each is shifted in phase by a factor relative to the angle from centerline. This is similar to the way the signals are combined in space.

Clearance and course signals are not separated in this monitoring technique. The output of the recombiner is an analog of that seen by an aircraft at the monitored angle. Figure 56 is a block diagram of the monitor system.

The monitor recombiner network was interfaced with the FA-8851 ILS Monitor detector and FA-8850 Localizer Monitor for the correlation tests. All tests were performed at the Ohio University Tamiami te t facility in Miami, Florida.

REQUIRED TESTS.

Monitor correlation tests were required for phase faults inserted in each antenna feedline in 15° increments from 15° to 45° and 3 dB attenuation faults inserted in each antenna feedline. In addition, a requirement exists that the system alarm for simulated open and shorted center conductors and each end of the antenna feedlines and monitor lines. The data taken for each fault is included in appendix A. All measurements in appendix A are ground measurements. Improved monitor correlation may be obtained with flight measurements.

The technique for monitoring the open and shorted center conductor faults is identical to that used in the Wilcox FA-9759/11 Cat III system.

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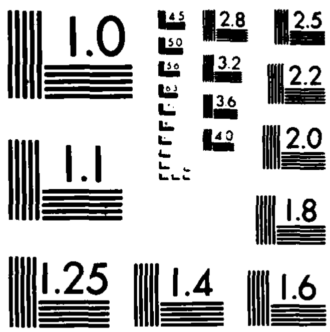
1.0
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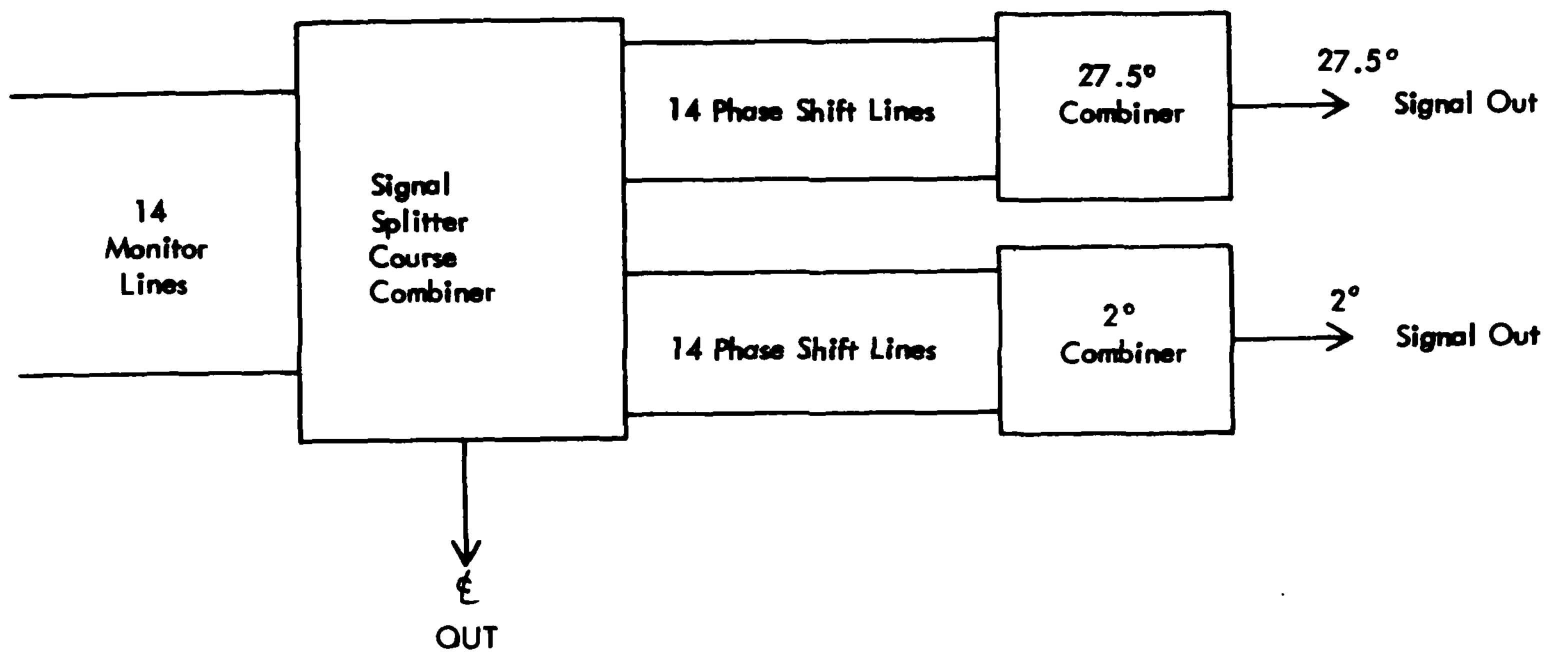

Figure 56. Block Diagram of Redlich Analog Monitor Recombiner.

This utilizes a DC continuity check of each antenna feedline through the antenna and monitor line. These tests were spot checked on the system to insure that an alarm would occur. All lines either opened or shorted resulted in an alarm condition.

CONCLUSIONS.

The monitor correlation test results indicate that the analog monitor will alarm prior to an out-of-tolerance condition for the course, width and clearance positions. In addition, RF level alarms for both the course and clearance transmitters can be adjusted to alarm for the required power reductions.

COMPARISONS OF MEASURED HORIZONTAL RADIATION PATTERNS OF THE WILCOX LOG PERIODIC DIPOLE, ALFORD O-RING, AND APC TRAVELING WAVE ANTENNAS

The traveling-wave type of localizer antenna has been a part of the FAA inventory for approximately 10 years. During this period several different types of localizer arrays have been designed using traveling-wave antennas as the radiating elements. The high directivity and low element-to-element coupling in these type antennas led to this use in the different arrays.

A localizer array designed to provide Category III quality at severe sites is currently being tested using the traveling-wave type antenna. The Wilcox Log Periodic Dipole (LPD) antenna is the more recent design of the traveling-wave type antennas and for this reason it was chosen as the element to be used in the design of the new array. In addition, the pattern for this type element was expected to be the same as those of the O-ring and TWA type antennas.

The wide-aperture, highly-directional localizer array designed by R. W. Redlich uses a fewer number of radiating elements in the large array apertures than any previous design. Using fewer elements with spacings greater than one wavelength means the possibility exists that the array would have a grating lobe near 60° in azimuth; however, using the published horizontal radiation patterns, calculations indicate that this grating lobe should be suppressed by the element at least -20 dB or better from the main lobes. Preliminary field testing on the wide-aperture arrays indicate that this side-lobe level is nearer the 12-15 dB level below the main lobe. The side-lobe level is, of course, critical in suppressing multipath, the fundamental purpose of the wide-aperture array. Because this side-lobe level is directly related to the single-element pattern, it has been deemed pertinent to make a comparison of the traveling-wave antenna patterns of the different manufacturers to determine if the grating lobe exists using elements other than the Wilcox LPD.

DISCUSSION.

Figure 57 is a plot of the Wilcox LPD horizontal radiation pattern. This pattern is duplicated from information supplied by Wilcox. The pattern is fairly symmetrical and the level at the 60° point is approximately -20 dB. This tends to indicate that the 60° grating lobe in the arrays should be -20 dB also. In addition, figure 58 shows the measured single element pattern as measured by Ohio University personnel. A disparity exists between the actual field pattern and the data as supplied by Wilcox. This results in the higher than expected grating lobe at 60°. See figure 59.

In figure 60 the horizontal pattern for the Alford O-ring element is shown. In this case, there is a null on one side of the element and the level on the opposite 60° point is -23 dB. Both of these points are lower than the Wilcox element by at least 10 dB. This fact alone would indicate

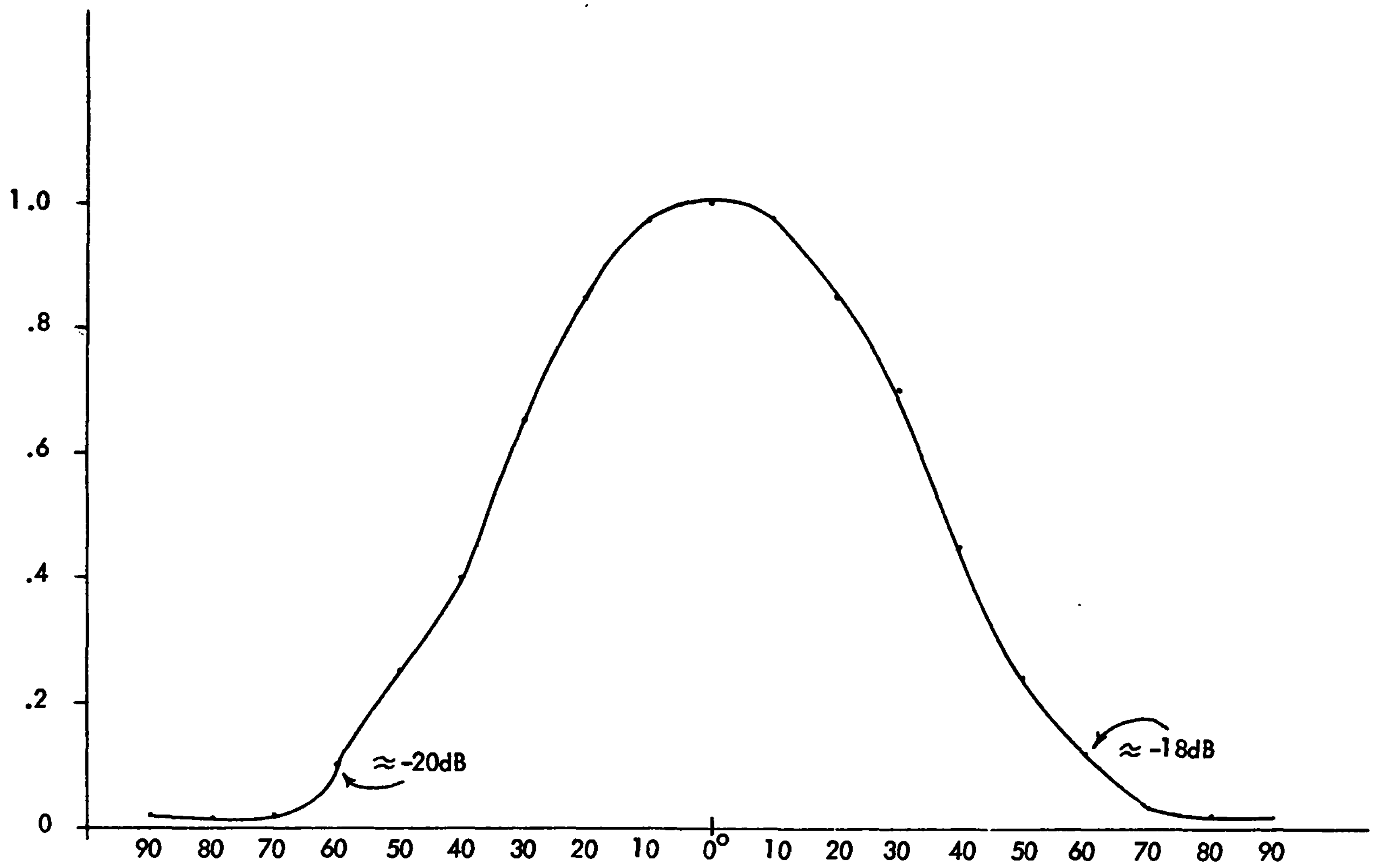

Figure 57. Measured Horizontal Radiation Pattern for the Wilcox LPD Localizer Antenna (Plotted from Information supplied by Wilcox).

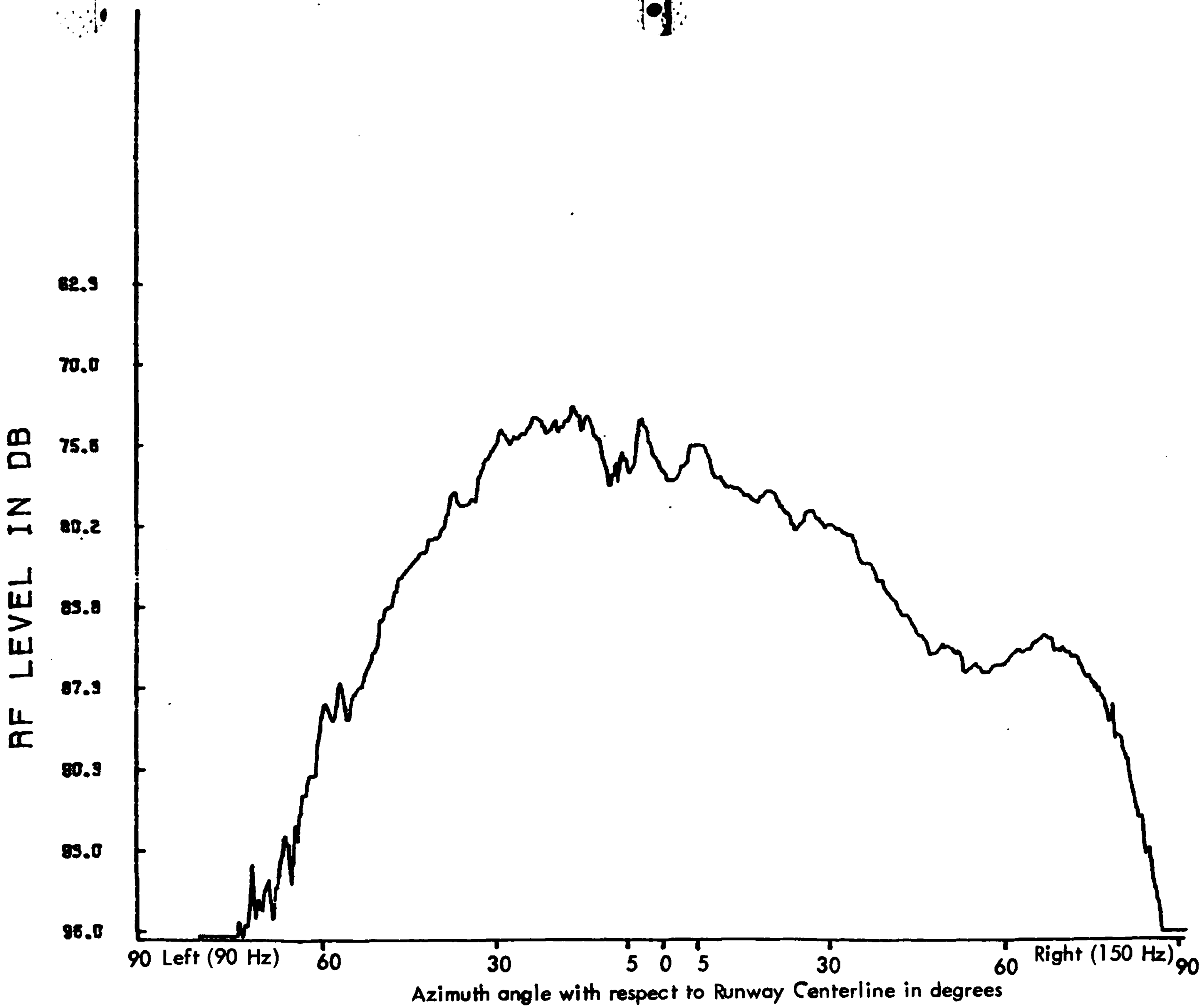

Figure 58. Calculated Horizontal Radiation Pattern Wilcox LPD (plotted from data supplied by Wilcox).

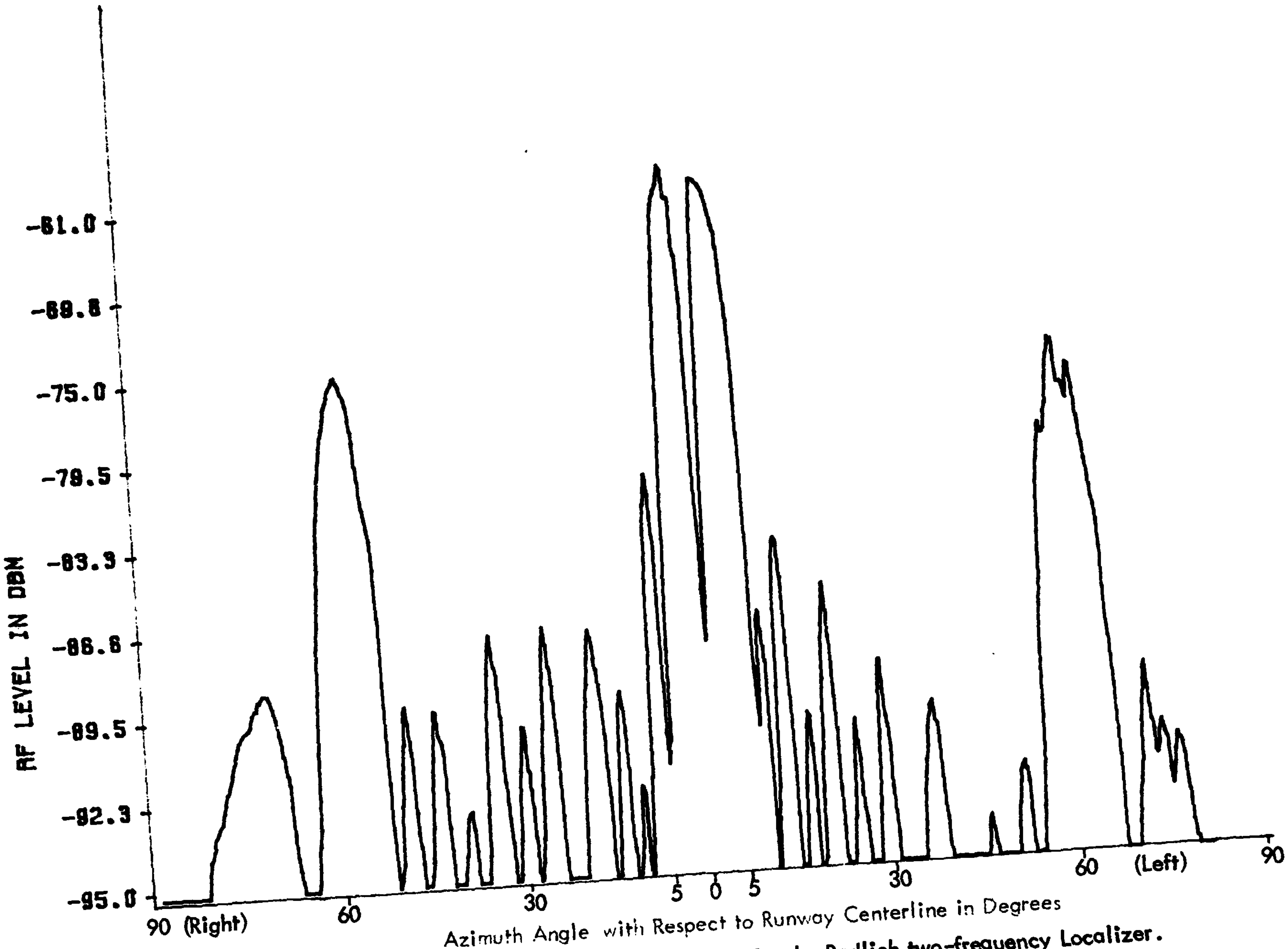

Figure 59. **Measured Sidebands Only Pattern for the Redlich two-frequency Localizer.**

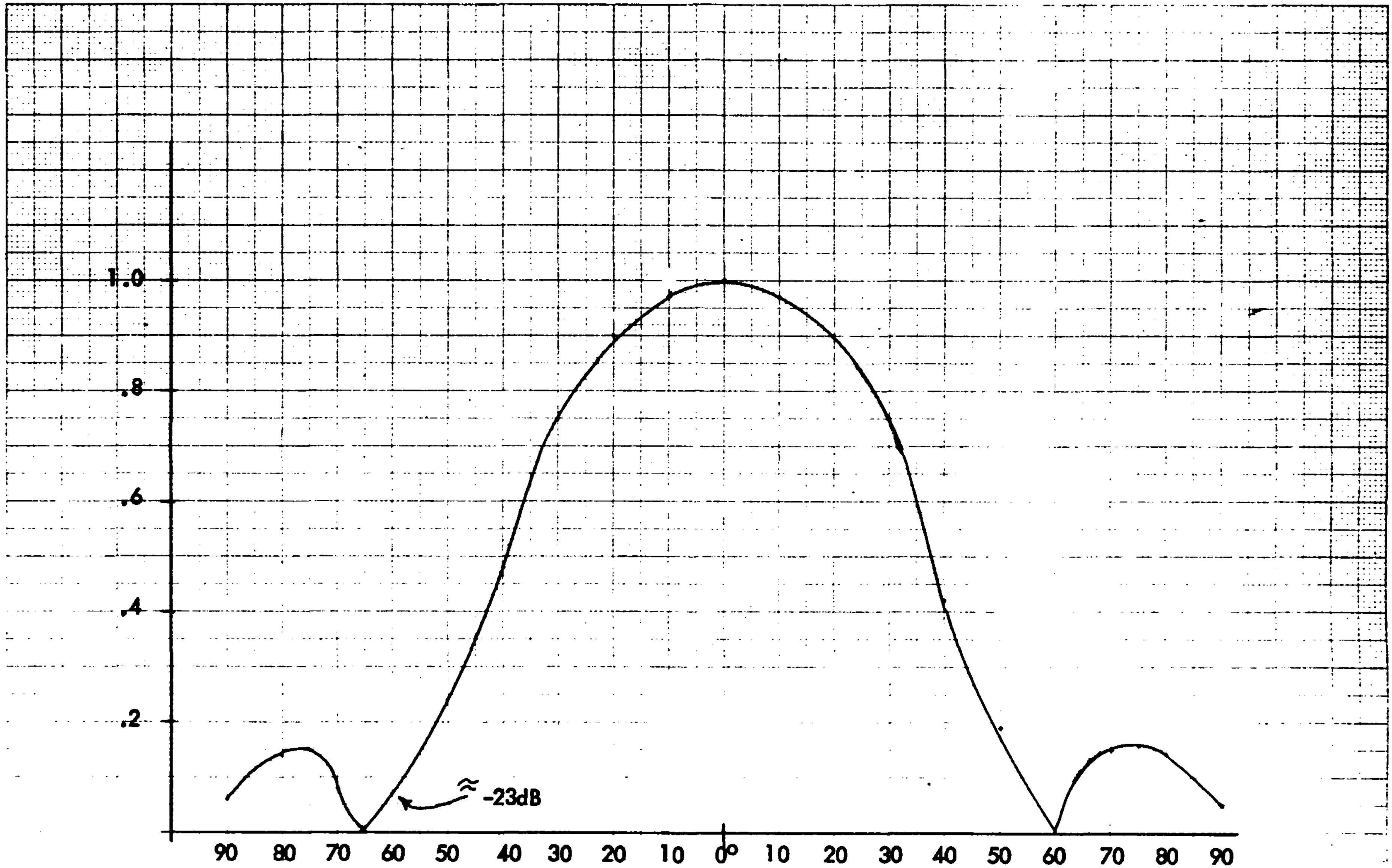

Figure 60. Measured Horizontal Radiation Pattern for the Alford O-Ring Localizer Antenna (Plotted from Polar Plot, pg. 17, Report No. FAA-RD-76-129, Peterson).

that much better performance could be expected from the Redlich array pattern of figure 59 using this element.

Figure 61 shows the same type of plot for the APC traveling-wave antenna. Figure 61 is plotted from published data, but in addition to this, field data has been collected on this particular element. See figure 62. Using the published data, the expected level at the 60° point would be at least -24 dB; however, the field data would indicate that a level of -17 dB would be present on one side of the array.

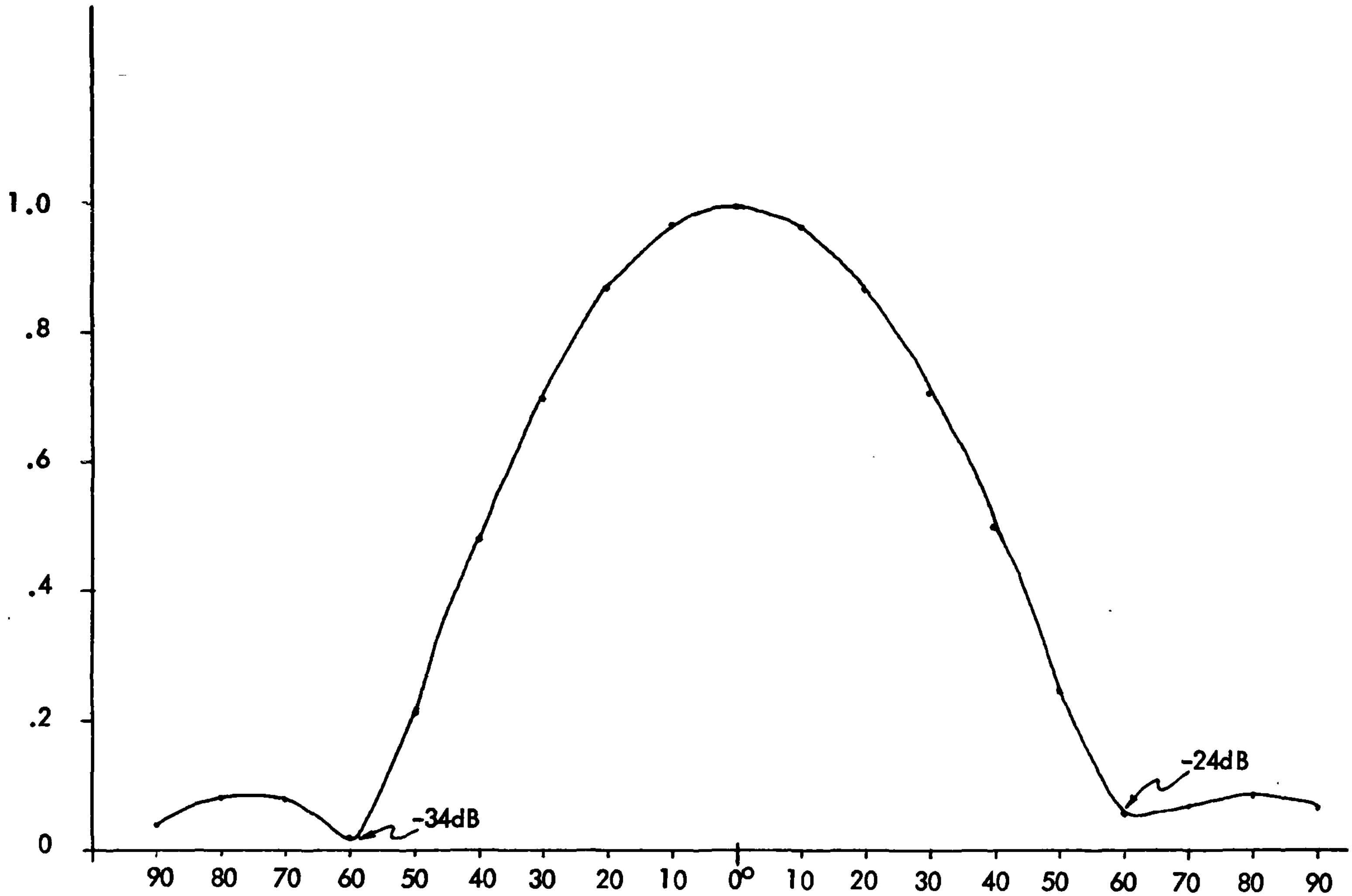

Figure 61. Measured Horizontal Radiation Pattern for the Localizer Traveling-Wave Antenna FA-9320 (Plotter from Polar Plot, pp. 1-19, TI 6750.96).

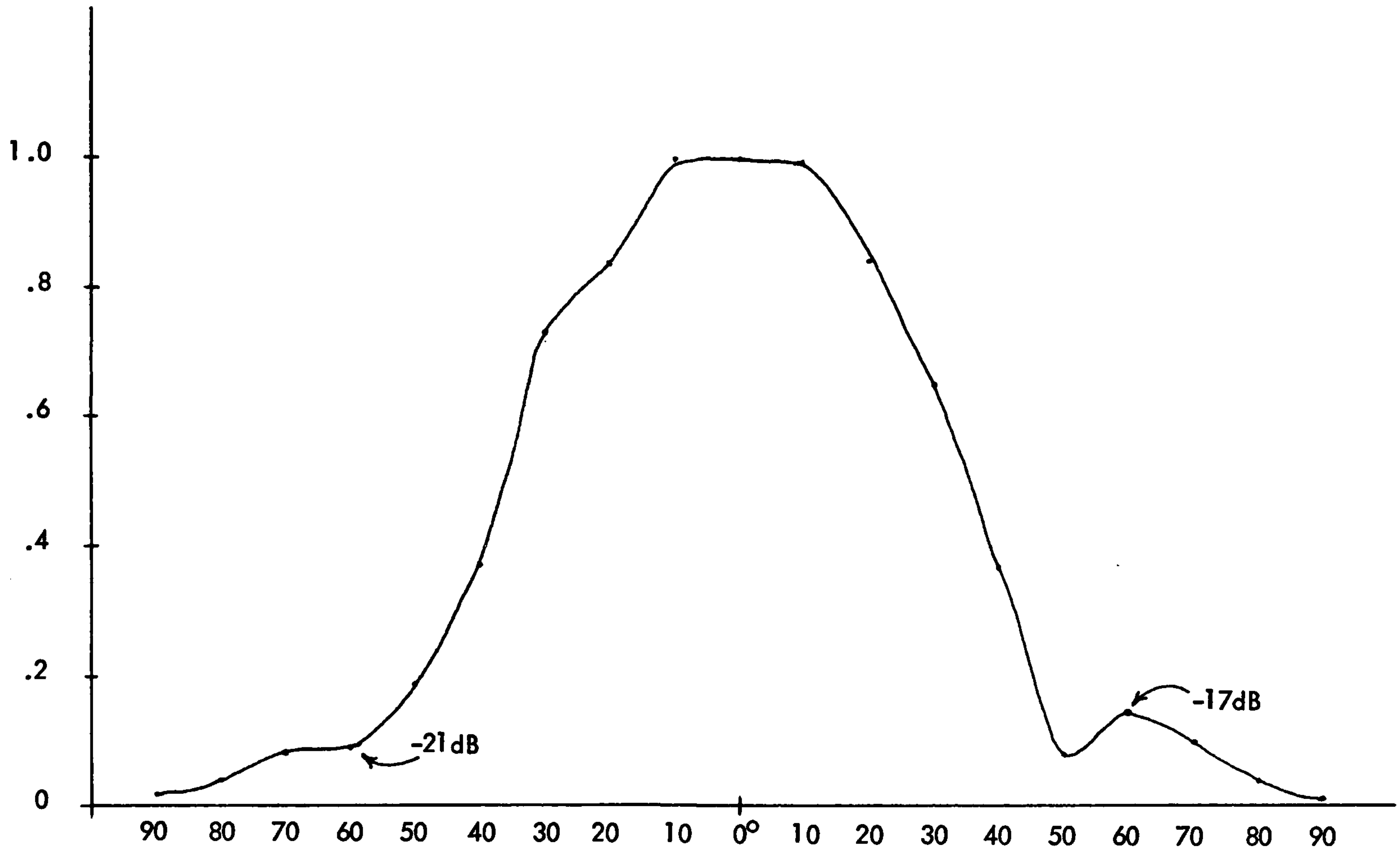

Figure 62. Measured Horizontal Radiation Pattern for the Localizer Traveling-Wave Antenna FA-9320. Plotted from field data collected at TMB test site April 29, 1981. Frequency = 111.9 MHz.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Mr. Walter Phipps, who served as the airborne panel operator and assisted on the installation. Installation assistance was also provided by Messrs. M. Jamil and J. Roman.

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Report production was furnished by Mms. Shirley Mellema, Joyce Longworth and Ann Breese. Mr. Samson Wong provided drafting support.

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[2] "In-Service Improvements and Modernization of All Components of the Instrument Landing Systems" Vol. I, Section V, Final Report, FAA-RD-78-112, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, July 1978.

[3] Op. cit. Peterson.

[4] Op. cit FAA-RD-78-112 Section V-B, E, F.

[5] Op. cit Peterson.

[6] Standard Flight Inspection Manual OA P 8200.1, Department of Transportation, Federal Aviation Administration.

Appendix A. Monitor Correlation Test Results

Test conducted at Tamiami Airport, Miami, Florida. Course and width far-field checks at 3500' using Ohio University's microlab in van. Clearance check using portable ILS receiver.

FAULT= 15 DEGREES AT 108.55 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.001	0.001	0.000	0.000	0.001	-0.002
6L	0.002	0.000	0.001	0.000	0.002	-0.001
5L	0.001	0.002	0.002	0.000	0.011	-0.008
4L	0.003	0.002	0.003	0.002	-0.013	0.002
3L	0.003	0.003	0.005	0.012	0.005	0.008
2L	0.004	0.004	0.007	0.014	-0.021	-0.032
1L	-0.004	0.004	0.009	0.014	0.053	0.042
1R	-0.004	-0.004	-0.006	-0.010	-0.086	-0.057
2R	-0.004	-0.002	-0.007	-0.011	0.053	0.010
3R	-0.004	-0.002	-0.007	-0.011	-0.037	-0.006
4R	-0.004	-0.002	-0.006	-0.007	0.026	-0.010
5R	-0.003	-0.002	-0.003	-0.004	-0.016	-0.001
6R	-0.002	0.000	-0.002	-0.001	0.011	0.001
7R	-0.002	0.000	0.000	-0.000	0.004	-0.003
NORMAL	0.004	0.000	0.136	0.150	0.247	0.190
RECHECK NORMAL	0.004	0.000	0.136	0.150	0.248	0.190

Table A-1. Change in Monitor and Far Field Readings.

FAULT= 30 DEGREES AT 108.55 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.000	0.005	0.000	-0.004	-0.003	-0.001
6L	0.003	0.003	0.002	-0.006	0.002	0.003
5L	0.004	0.004	0.004	0.002	0.012	-0.010
4L	0.004	0.005	0.006	0.010	-0.024	0.004
3L	0.006	0.005	0.010	0.019	-0.003	0.017
2L	0.006	0.006	0.013	0.021	-0.036	-0.057
1L	0.007	0.006	0.016	0.023	0.012	0.062
1R	-0.003	-0.005	-0.011	-0.018	-0.137	-0.092
2R	-0.006	-0.005	-0.011	-0.020	0.052	0.015
3R	-0.008	-0.006	-0.011	-0.019	-0.073	-0.006
4R	-0.005	-0.005	-0.008	-0.018	0.043	-0.015
5R	-0.006	-0.004	-0.006	-0.013	-0.033	-0.001
6R	-0.006	-0.003	-0.004	-0.005	0.016	0.003
7R	-0.002	0.000	-0.001	-0.002	0.000	-0.004
NORMAL	0.004	0.000	0.136	0.150	0.248	0.187
RECHECK NORMAL	0.005	0.000	0.136	0.150	0.248	0.187

Table A-2. Change in Monitor and Far Field Readings.

FAULT= 45 DEGREES AT 108.55 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.002	0.002	0.001	-0.003	-0.005	-0.004
6L	0.004	0.004	0.001	-0.007	0.003	0.007
5L	0.007	0.007	0.006	0.002	0.008	-0.019
4L	0.008	0.003	0.009	0.012	-0.033	0.000
3L	0.009	0.009	0.014	0.031	-0.029	0.026
2L	0.009	0.007	0.019	0.039	-0.048	-0.093
1L	0.013	0.010	0.025	0.038	-0.132	-0.001
1R	-0.011	-0.008	-0.018	-0.024	-0.188	-0.138
2R	-0.008	-0.006	-0.014	-0.020	0.052	0.008
3R	-0.008	-0.008	-0.015	-0.026	-0.120	-0.007
4R	-0.007	-0.007	-0.011	-0.018	0.052	-0.024
5R	-0.006	-0.007	-0.010	-0.016	-0.051	-0.004
6R	-0.006	-0.004	-0.007	-0.006	0.025	0.006
7R	-0.003	-0.002	-0.002	-0.003	-0.003	-0.007
NORMAL	0.005	0.000	0.136	0.148	0.248	0.189
RECHECK NORMAL	0.005	0.000	0.136	0.148	0.248	

Table A-3. Change in Monitor and Far Field Readings.

FAULT = 3DB AT 108.55 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	-0.001	-0.003	-0.003	-0.003	-0.003	-0.010
6L	-0.002	-0.004	-0.007	-0.012	0.018	0.021
5L	-0.002	-0.004	-0.003	-0.007	-0.015	-0.005
4L	-0.004	-0.004	-0.007	-0.019	-0.002	-0.034
3L	-0.006	-0.006	-0.004	-0.012	-0.129	0.041
2L	-0.007	-0.004	-0.006	0.000	-0.008	-0.032
1L	-0.017	-0.005	-0.005	0.012	-0.360	-0.251
1R	0.005	0.003	0.007	0.013	-0.014	-0.004
2R	0.008	0.004	0.012	0.035	0.038	-0.114
3R	0.005	0.004	0.012	0.008	-0.127	0.014
4R	0.003	0.004	0.000	-0.005	0.021	-0.019
5R	0.002	0.001	0.000	-0.003	-0.011	-0.006
6R	0.002	0.001	-0.002	-0.003	0.012	0.005
7R	0.003	0.001	-0.003	-0.008	-0.012	-0.010
NORMAL	0.005	0.001	0.136	0.148	0.248	0.191
RECHECK NORMAL	0.004	0.001	0.136	0.148	0.248	0.191

Table A-4. Change in Monitor and Far Field Readings.

FAULT= 15 DEGREES AT 109.7 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.001	0.004	0.001	0.003	-0.004	
6L	0.001	0.004	0.002	0.005	-0.001	
5L	0.002	0.000	0.003	0.000	0.004	
4L	0.002	0.007	0.005	0.010	-0.013	
3L	0.003	0.003	0.007	0.015	0.002	
2L	0.003	0.005	0.009	0.020	-0.021	
1L	0.005	0.002	0.012	0.012	0.035	
1R	-0.007	-0.007	-0.006	-0.008	-0.096	
2R	-0.004	-0.004	-0.006	-0.009	0.035	
3R	-0.005	-0.006	-0.007	-0.015	-0.045	
4R	-0.004	-0.004	-0.003	-0.010	0.025	
5R	-0.004	-0.007	-0.003	-0.005	-0.020	
6R	-0.003	0.000	-0.002	0.007	0.008	
7R	-0.002	-0.005	0.000	-0.005	0.000	
NORMAL	0.001		0.141		0.265	
RECHECK NORMAL	0.001		0.142		0.269	

Table A-5. Change in Monitor Readings, No Far Field Readings for Clearance At This Frequency.

FAULT= 30 DEGREES AT 109.7 MHZ

ANTENNA NUMBER	COURSE MON	COURSE FF	WIDTH MON	WIDTH FF	CLEARANCE MON	CLEARANCE FF
7L	0.002	0.000	0.000	0.001	-0.002	
6L	0.003	0.005	0.003	0.001	0.005	
5L	0.005	0.005	0.006	0.007	0.007	
4L	0.006	0.007	0.006	0.018	-0.025	
3L	0.007	0.010	0.012	0.020	-0.009	
2L	0.008	0.007	0.012	0.025	-0.038	
1L	0.012	0.007	0.020	0.020	0.014	
1R	-0.011	-0.004	-0.012	-0.015	-0.147	
2R	-0.007	-0.003	-0.010	-0.016	0.037	
3R	-0.006	-0.005	0.011	-0.015	-0.081	
4R	-0.005	-0.004	0.007	-0.012	0.037	
5R	-0.004	-0.005	0.006	-0.005	-0.036	
6R	-0.004	0.000	0.004	-0.001	0.010	
7R	-0.002	0.000	0.001	0.000	-0.004	
NORMAL	0.002		0.142		0.263	
RECHECK NORMAL	0.002		0.142		0.260	

Table A-6. Change in Monitor and Far Field Readings, No Far-Field Clearance Readings At this Frequency.

FAULT= 45 DEGREES AT 109.7 MHZ

ANTENNA NUMBER	COURSE MON	COURSE FF	WIDTH MON	WIDTH FF	CLEARANCE MON	CLEARANCE FF
7L	0.003	0.004	0.000	0.000	-0.004	
6L	0.005	0.006	0.000	-0.004	0.004	
5L	0.006	0.007	0.005	-0.004	0.001	
4L	0.008	0.010	0.007	0.012	-0.029	
3L	0.009	0.010	0.014	0.031	-0.033	
2L	0.010	0.010	0.016	0.040	-0.042	
1L	0.019	0.010	0.031	0.033	-0.054	
1R	0.017	-0.005	-0.021	-0.020	-0.196	
2R	0.009	-0.005	-0.013	-0.025	0.042	
3R	0.009	-0.005	-0.016	-0.030	-0.124	
4R	0.007	-0.005	-0.013	-0.018	0.042	
5R	0.006	-0.007	-0.011	-0.015	-0.051	
6R	0.005	-0.002	-0.008	-0.005	0.027	
7R	0.002	0.000	-0.003	-0.001	0.001	
NORMAL	0.002		0.143		0.258	
RECHECK NORMAL	0.002		0.142		0.258	

Table A-7. Change in Monitor and Far Field Readings, No Far Field Readings for Clearance at This Frequency.

FAULT= 3DB AT 109.7 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.000	-0.004	-0.001	0.002	-0.002	
6L	0.000	-0.001	-0.001	0.002	0.002	
5L	-0.001	-0.002	-0.001	0.003	-0.017	
4L	-0.004	-0.007	-0.007	-0.010	-0.005	
3L	-0.007	-0.008	-0.005	-0.008	-0.140	
2L	-0.004	-0.002	-0.002	0.003	0.028	
1L	-0.006	-0.005	-0.006	-0.002	-0.104	
1R	0.003	0.003	0.010	0.012	0.038	
2R	0.003	0.002	0.009	0.014	-0.011	
3R	0.003	0.000	0.008	0.005	-0.025	
4R	0.002	0.003	0.003	0.002	-0.005	
5R	0.001	0.001	0.001	0.000	-0.012	
6R	0.000	0.002	0.000	0.000	0.006	
7R	0.000	0.001	0.000	-0.001	0.000	
NORMAL	0.001		0.142		0.262	
REHECK NORMAL	0.002		0.141		0.254	

Table A-8. Change in Monitor and Far Field Readings, No Far Field Clearance Readings for this Frequency.

FAULT = 15 DEGREES AT 111.9 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.001	0.003	-0.002	-0.001	0.000	-0.005
6L	0.003	0.004	-0.002	-0.004	0.004	0.001
5L	0.002	0.004	0.002	0.000	-0.001	-0.013
4L	0.004	0.005	0.004	0.006	-0.003	0.003
3L	0.004	0.005	0.006	0.007	-0.008	0.017
2L	0.004	0.006	0.008	0.010	-0.001	-0.043
1L	0.006	0.006	0.017	0.010	0.083	0.047
1R	-0.005	0.000	-0.012	-0.008	-0.076	-0.066
2R	-0.005	0.000	-0.012	-0.015	0.042	0.017
3R	-0.004	0.000	-0.010	-0.014	-0.024	-0.004
4R	-0.004	0.000	-0.008	-0.011	0.012	-0.016
5R	-0.003	0.000	-0.005	-0.005	-0.009	-0.003
6R	-0.003	0.000	-0.003	-0.004	-0.003	-0.003
7R	-0.001	0.000	-0.001	-0.001	0.003	-0.010
NORMAL	0.005	0.000	0.170	0.150	0.205	0.201
RECHECK NORMAL	0.005	0.001	0.170	0.150	0.203	0.195

Table A-9. Change in Monitor and Far Field Readings.

FAULT = 30 DEGREES AT 111.9 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.004	0.002	0.000	-0.001	0.000	-0.010
6L	0.006	0.002	-0.001	-0.004	0.011	0.020
5L	0.008	0.003	0.006	0.000	0.000	-0.020
4L	0.008	0.005	0.006	0.010	-0.004	0.000
3L	0.009	0.005	0.010	0.019	-0.016	0.050
2L	0.010	0.006	0.017	0.027	-0.003	-0.080
1L	0.013	0.006	0.034	0.028	0.097	0.110
1R	-0.007	-0.007	-0.018	-0.023	-0.116	-0.130
2R	-0.006	-0.005	-0.021	-0.027	0.097	0.010
3R	-0.006	-0.005	-0.018	-0.022	-0.044	0.010
4R	-0.006	-0.003	-0.011	-0.019	0.026	-0.020
5R	-0.003	-0.003	-0.009	-0.012	-0.014	-0.010
6R	-0.002	-0.001	-0.004	-0.008	-0.002	0.000
7R	-0.001	0.000	-0.001	-0.003	0.010	0.000
NORMAL	0.003	0.000	0.167	0.150	0.203	0.240
RECHECK NORMAL	0.001		0.167		0.207	0.240

Table A-10. Changes in Monitor and Far Field Readings.

FAULT = 45 DEGREES AT 111.9 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.003	0.002	-0.002	-0.006	-0.005	-0.020
6L	0.005	0.005	-0.004	-0.003	0.016	0.010
5L	0.007	0.006	0.005	-0.002	-0.011	-0.040
4L	0.011	0.009	0.007	0.013	-0.008	-0.020
3L	0.010	0.008	0.012	0.025	-0.043	0.070
2L	0.011	0.009	0.022	0.041	-0.005	-0.150
1L	0.019	0.007	0.053	0.028	0.008	0.110
1R	-0.015	-0.007	-0.030	-0.022	-0.162	-0.180
2R	-0.011	-0.009	-0.029	-0.031	0.093	-0.010
3R	-0.011	-0.008	-0.027	-0.029	-0.088	-0.010
4R	-0.009	-0.009	-0.016	-0.025	0.042	-0.040
5R	-0.008	-0.006	-0.011	-0.016	-0.032	-0.010
6R	-0.005	-0.006	-0.009	-0.012	0.002	0.000
7R	-0.002	-0.002	0.000	-0.004	0.003	-0.010
NORMAL	0.001	0.001	0.167	0.149	0.207	0.240
RECHECK NORMAL	0.001	0.000	0.167	0.147	0.205	

Table A-11. Change in Monitor and Far Field Readings.

FAULT = 3DB AT 111.9 MHZ

ANTENNA	COURSE		WIDTH		CLEARANCE	
NUMBER	MON	FF	MON	FF	MON	FF
7L	0.000	0.000	0.000	-0.002	0.004	-0.010
6L	0.000	-0.002	-0.003	-0.005	0.005	0.010
5L	0.000	-0.001	-0.003	-0.006	-0.011	-0.020
4L	0.000	-0.002	-0.005	-0.004	0.013	-0.030
3L	0.000	-0.002	-0.004	-0.003	-0.025	0.020
2L	-0.002	-0.002	-0.005	0.002	0.030	-0.010
1L	-0.002	0.000	0.002	0.002	-0.081	-0.060
1R	0.005	0.000	-0.019	0.009	-0.038	0.000
2R	0.003	0.000	0.011	0.008	0.037	-0.050
3R	0.002	-0.001	0.000	0.003	-0.037	0.020
4R	0.004	0.001	-0.005	-0.009	0.059	-0.020
5R	0.002	0.000	-0.008	-0.012	-0.056	-0.040
6R	0.000	0.002	-0.015	-0.014	0.044	0.020
7R	0.001	0.001	-0.005	-0.007	-0.010	-0.010
NORMAL	0.001	0.002	0.167	0.148	0.205	0.240
RECHECK NORMAL	0.001		0.167		0.205	

Table A-12. Change in Monitor and Far Field Readings.

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